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AN ANALYSIS OF THE INTERNATIONAL GREAT LAKES LEVELS BOARD REPORT ON REGULATION OF GREAT LAKES WATER LEVELS

Hydrology

Water Resources Management Workshop
and
Lake Superior Project

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University of Wisconsin Madison

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WISCONSIN COASTAL MANAGEMENT

AN ANALYSIS OF THE INTERNATIONAL GREAT LAKES LEVELS BOARD REPORT ON REGULATION OF GREAT LAKES WATER LEVELS

HYDROLOGY

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Errata Sheet

October 25, 1976

RF Monograph 76-01 — Hydrology
IES Working Paper 27

Pages 6 & 106: Title should be: Monthly Diversions into Lake Superior and Out of Lake Michigan.

Page 99: Paragraph 3, line 3 is changed to: . . . by 0.5 to 0.7 feet below

Page 111: In Table 39, first column, line 3. Circle -.97.

RF Monograph 76-06 — Summary
IES Working Paper 32

Page 14: Paragraph 2 should be:

These climate changes result from alterations of upper air circulation patterns which are responsible for the high variability in net basin supplies and related lake levels since approximately 1960. Due to the limitations of present forecasting technology, it is impossible to accurately predict how long the present period of high supplies might last, but the present trend toward cooler and wetter conditions, which has occurred since approximately 1950, is likely to continue during the next few decades. Thus, while long-term fluctuations do not occur in regular cycles, there are periods when high or low lake levels persist (RF Monograph 76-01—Hydrology, section III).

Page 21: Last paragraph, line 9 should be:

. the IGLLB established stage-damage curves for each of 36 United States reaches

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For further information about the publications, write to:

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TABLES

FIGURES

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I. HYDROLOGY SYNTHESIS
PART I: DATA BASE AND PLANS

INTRODUCTION

The regulation of water levels in the Great Lakes is a subject that has recently received much attention by the states directly affected by lake level fluctuations. This section deals with the hydrology of the Great Lakes system and lays the foundation for the subsequent analysis of shore property, navigation, and wetlands.

Since the Great Lakes system is both extensive in area and extremely complex, the hydrologic investigation was limited primarily to Lakes Superior and Michigan-Huron. A map of the Great Lakes system showing the drainage basins and the principal controls is presented in Figure 1. Time did not permit a more comprehensive study of the lower lake system nor an analysis of all the alternative regulation plans developed in the International Great Lakes Levels Board (IGLLB) report. This report includes analyses of Plans SO-901, SO-901 Mod 7, SO-901 Mod 8, SEO-42P, and SEO-17P, and the Basis-of-Comparison (BOC) Model. The effects of the long-term climate variations on net basin supplies to the Great Lakes are also examined.

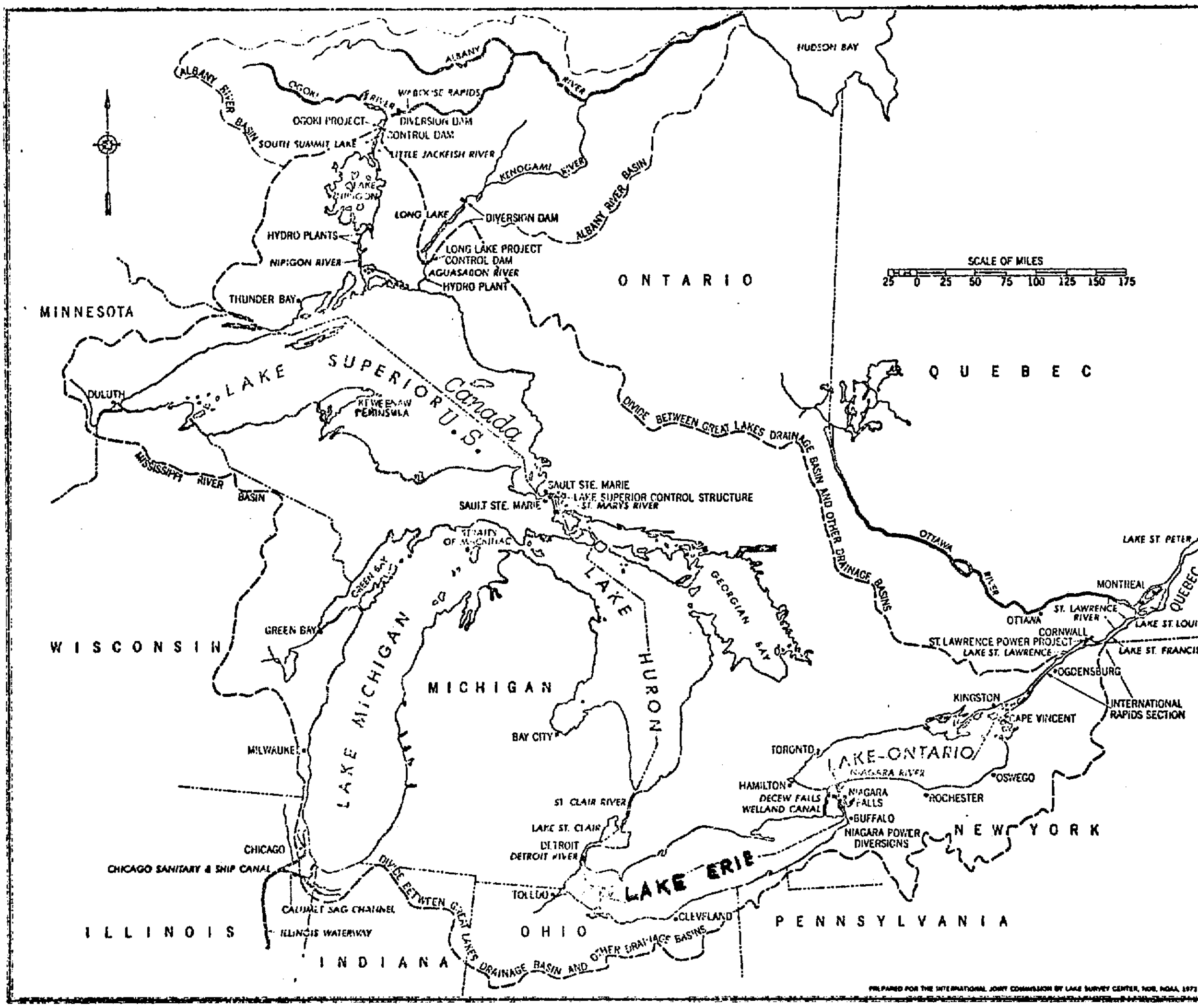
A. STATEMENT OF THE PROBLEM

The fluctuations of water levels on the Great Lakes are influenced by natural causes and by structural controls of man. The major natural causes include precipitation, evaporation, runoff, and groundwater. The principal man-induced causes relate to the effects of dams and locks and to diversions. A period characterized by water level extremes, albeit very high or very low, is normally accompanied by abundant complaints that artificial controls are the major factors responsible for deviations of levels from the average. This paper and its appendices address problems related to identifying the relative importance of natural and man-induced causes of lake level fluctuations.

B. HISTORICAL BACKGROUND

In the early 1960s, the levels of the Great Lakes were extremely low relative to the range of levels observed over the historical record of lake level measurement. The lower levels were interfering with hydroelectric power production, navigation, and recreational shoreline uses. Consequently, in October 1964, the governments of the United States and Canada submitted a joint reference to the International Joint Commission (IJC) concerning the water levels of the Great Lakes. As a result of this reference, the IJC created the IGLLB, the International Great Lakes Levels Board, and directed it to evaluate the problems associated with low lake levels and to develop a system of lake level regulation that would reduce the damages that were occurring to the entities involved with Great Lakes resources. In order to accomplish this task, extensive lake regulation schemes were developed which were intended to decrease the variation of lake levels and to maximize benefits to the Great Lakes basin as a whole.

FIGURE 1 GREAT LAKES — ST. LAWRENCE RIVER DRAINAGE SYSTEM



Source: IGLLB 1973, Appendix B, p. B-2.

In the early 1970s lake levels again became an issue of major concern, but this time the concern was related to unusually high levels. The high levels primarily increased the incidence of shore erosion damages. In order to assess the effects of lake regulation in Wisconsin a study of the IGLLB report was undertaken by the Water Resources Management (WRM) workshop and the Lake Superior Project of the Institute for Environmental Studies, both at the University of Wisconsin-Madison. The University, in conjunction with the Wisconsin State Department of Administration's Coastal Zone Management staff and representatives from the Department of Natural Resources, worked to elucidate implications of lake level regulation for the state of Wisconsin.

The objective of the University effort was to analyze Plans SO-901, SO-901 Mod 7, SO-901 Mod 8, and Plans SEO-17P and SEO-42P. The hydrologic aspects of the various plans were evaluated in terms of their physical impacts on the Great Lakes resources of the state of Wisconsin. The hydrology subgroup devoted much of their time to reviewing the Basis-of-Comparison Model, Plans SO-901, and its alternatives Mod 7 and Mod 8. These analyses required the use of computer simulation programs which were supplied by the U.S. Army Corps of Engineers (Corps).

C. Data Base and the Basis-of-Comparison

The observed historical record of lake levels are unsuitable as a data base for assessing the impact of proposed lake level management schemes because observed levels reflect many different effects of earlier regulation plans. Therefore, the IGLLB simulated a data base to serve as a basis-of-comparison for evaluating the effects of proposed management schemes. The Basis-of-Comparison data set was simulated by routing through the system net basin supplies estimated from available data on lake levels, diversions, and outflow measurements as recorded for the period 1900-1967. The BOC data base represents an artificially regulated lake system, and therefore is not a reconstruction of lake levels free of man's influence. The BOC regulation plan utilizes the September 1955 Modified Rule of 1949 to control the release of water from Lake Superior into Lakes Michigan and Huron. A constant diversion of 5,000 cfs* into Lake Superior from Long Lake and the Ogoki River and a constant diversion of 3,200 cfs out of Lake Michigan at Chicago were also included in the BOC simulation. The BOC plan incorporates hydrologic conditions which existed at the outlet of Lake Huron in 1962 for evaluations involving the "SO" plans. Evaluation of regulation plans that involve major construction in the Great Lakes system assumed 1933 outlet conditions for Lake Huron in the BOC simulation. Other inclusions in the BOC standardized regulation included: (a) a constant diversion of 7,000 cfs out of Lake Erie into Lake Ontario via the Welland Canal, (b) 1953 outlet conditions for Lake Erie, and (c) Lake Ontario regulated in accordance with Plan 1958-D (except with discretionary authority after 1960) and for 1955 outlet conditions. The IGLLB chose the 1900-1967 data base because the Levels Board believed that it represented the earliest date of reliable data and because the period was thought to have incorporated considerable extremes of net basin supplies.

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*Cubic Feet per Second - cfs.

D. Major Regulation Plans

Although the IGLLB studied a relatively large number of regulation plans, only the principal plans which have the greatest impacts on Lakes Superior, Michigan, and Huron are evaluated in the present investigation. Plan SO-901, because of its emergence as "most favored," is given the most attention.

Plan SO-901. Plan SO-901 incorporates a "balancing" concept in the regulation of Lake Superior and Lakes Michigan and Huron. The balancing concept calls for the maintenance of the levels of Lakes Superior, Michigan, and Huron as close as possible to their respective long-term mean levels. Under the rules of the plan, the standard deviations of the beginning-of-the-month levels for both Lake Superior and Lakes Michigan and Huron are calculated and compared to determine which of the two lake systems represents the larger deviation from long-term respective mean levels of the lake. The lake having the largest deviation is considered to be in an unfavorable condition relative to the other lake and Lake Superior outflow is regulated in favor of returning the lake having the greater deviation closer to its long-term mean level. The magnitude of the outflow is first approximated by a linear equation whose parameters are based upon the means and standard deviations of levels for the two lake systems. After determination of the initial Lake Superior outflow from the equation, the actual release is adjusted, if necessary, to meet certain limitations set by hydrologic impacts on power production, navigation, and shore property interests. These limitations include: (a) maximum outflow for May-November to be 65,000 cfs plus 16 gates open, (b) maximum outflow for December-April to not exceed 85,000 cfs, (c) minimum outflow for any month to not drop below 55,000 cfs, and (d) change in outflow from month to month to be limited to 30,000 cfs.

Plan SO-901 is relatively similar to the Modified Rule of 1955 which represented the regulation policy regarding the discharge of water from Lake Superior until 1973. The principal difference between the 1955 Modified Rule and Plan SO-901 relates to the incorporation of Lakes Michigan and Huron levels into the determination of the Lake Superior discharge. The flow limitations described in (a) through (d) above are the same for the two regulation plans, but the discharges under the Modified Rule of 1955 are initially determined only from deviations of Lake Superior levels from the long-term mean level.

Plan SO-901, Mod 7 and Mod 8. Modifications of Plan SO-901 were examined to determine if additional benefits could be obtained under the general rules of regulation set by Plan SO-901. Two of the alternative plans, which emerged as having favorable cost/benefit ratios, involved increasing the range of permissible levels on Lake Superior to improve benefits on downstream lakes. The plans assumed that lowering of the minimum levels on Lake Superior could be accommodated by navigation, providing all channels and harbors in Lake Superior and the St. Marys River were dredged. Relative to Plan SO-901, Mod 7 regulation has the effect of lowering the mean level of Lake Superior by 0.5 feet and increasing the variance about the mean by 25% while reducing the variance about Lakes Michigan and Huron mean by 30%. Relative to Plan SO-901, Mod 8 has the effect of lowering the mean level of Lake Superior by 0.8 feet and increasing the variance about the mean by 25% while reducing the variance about Lakes Michigan and Huron mean by 35%. Both Mods 7 and 8 utilize the present set of structural controls in the St. Marys River system. Test results on two other Mod plans which involved increasing the channel capacity of the St. Marys River did not indicate benefits which would offset the costs of construction.

Plans SEO-17P and SEO-42P. The SEO plans involve coordinated regulation of the three lakes, Superior, Erie, and Ontario. Plans SEO-17P and SEO-42P were the results of a study which demonstrated that favorable benefits could be achieved by lowering the mean level of Lake Erie through channel enlargement in the upper Niagra River associated with regulation of Lakes Superior and Ontario in accordance with Plan SO-901. Other SEO regulation plans which attempted to reduce the range of stage in Lake Erie through structural controls did not produce favorable benefits.

The channel enlargements for these two SEO plans were to be achieved by dredging a diversion channel across Squaw Island to provide an additional connection between the Black Rock Canal and the upper Niagara River near the outlet from Lake Erie. Under Plan SEO-42P the diversion would normally be utilized to pass an additional outflow of 8,000 cfs from Lake Erie during periods of excessive supplies. Plan SEO-17P, which constitutes a revised version of SEO-42P, allows for increasing the magnitude of the diversion, during periods of excessive supplies, up to 17,500 cfs in the months of January through April and up to 10,000 cfs extra diversion during the months of May through December.

E. Diversions

The diversion of water into and out of the Great Lakes is also an alternative that can provide some relief during periods characterized by extremely high or low lake levels. Water is currently being diverted into Lake Superior via Long Lake and from the Ogoki River, both in Ontario, Canada. The Canadian diversions average about 5,000 cfs. The diversions into Lake Superior have ranged in magnitude from an average of over 15,000 cfs for some months of record to zero discharge during some periods of excessive net basin supplies. Water is also currently being diverted out of Lake Michigan through the Chicago Sanitary and Ship Canal to the Illinois River. The Chicago diversion was maintained at an approximate average monthly discharge of 10,000 cfs during its early period of operation, but in the past few years it has been restricted to an average monthly discharge of 3,200 cfs. The diversions have traditionally been viewed primarily in relation to national interests. As a result, alternative management policies which might be applied to the diversions are poorly understood.

PART II: HYDROLOGIC IMPACTS OF PROPOSED PLANS—SUMMARY

The hydrology working paper consists of a series of reports which summarize investigations of specific hydrologic problems related to various management alternatives proposed by the IGLLB Main Report (1973). The specific purpose of this section is to highlight the principal impacts of the proposed management plans and to provide an integration of their characteristics in relation to management of the Great Lakes as a system.

A. CHARACTERISTICS OF THE DATA BASE

The Lake Levels Board, in choosing to examine a data base of lake levels spanning the years 1900-1967, were faced with the problem that artificial controls affecting lake levels had changed several times over the 67-year span. The Levels Board circumvented this problem by standardizing the data in relation to specific artificially regulated conditions as described in Part I of this hydrology summary report. It is important to recognize that comparative analyses which judge the impacts of specific lake level management schemes do not measure the impacts of management against unaltered natural conditions on the lakes because the benchmark data base constitutes an artificially regulated system. Specific characteristics of the Basis-of-Comparison (BOC) data base differ somewhat depending upon whether the management plan being assessed involves either structural or nonstructural regulatory controls. It is possible to estimate the gross difference between the BOC base and the anticipated natural base from lake level data which relate to the 1887 natural outlet conditions in the St. Marys River (IGLLB 1973, Main Report, p. 48). The IGLLB data suggest that the effect of the September 1955 Modified Rule of 1949, which is the principal part of the BOC regulatory scheme for Lake Superior, has probably increased the overall mean level on Lake Superior by approximately 0.34 feet. The IGLLB Main Report (1973, pp. 48, 102) data also suggest that when 1962 outlet conditions for Lake Huron are assumed in the BOC, the levels of Lakes Michigan and Huron are 0.61 feet lower than levels generated utilizing the unregulated 1887 conditions. It may be concluded that the BOC regulation effects have resulted in an increase of the level of Lake Superior and a decrease of the level of Lakes Michigan and Huron compared to levels anticipated for natural outlet conditions.

The University team compared the degree to which the Basis-of-Comparison simulated lake levels and approximated the actual recorded levels on Lake Superior and on Lakes Michigan and Huron. The comparative analysis, which was restricted to the 1961-1973 time span, revealed that the BOC levels were generally close to recorded levels although occasional deviations were apparent. The BOC levels for Lakes Michigan and Huron were almost always found to be 0.05 to 0.20 feet below the observed levels, the largest difference being about 0.30 feet below. The departures of the simulated BOC levels from observed levels on Lake Superior were somewhat more variable than observed for Lakes Michigan and Huron. However, with the exception of the period 1965-1967, when the BOC produced levels above those actually observed, and the period 1970-1973, when the BOC produced levels significantly below those actually observed, the BOC simulation produced levels which were in close agreement with actual levels. The greatest departure, above or below the observed levels was about 0.35 feet. The larger differences were found to be related to deviations from the operating rule during periods of abnormal net basin supplies. While there is some concern that the BOC simulation may underestimate levels in periods of abnormally high net basin supplies, it may be concluded that over the long term the BOC levels are generally similar to observed levels, although a comparison of August mean levels on Lake Superior against BOC August levels for the period 1911-1960 reveals that recorded levels frequently exceeded BOC levels by at least 0.3 feet. It is possible that a tendency for BOC levels to be somewhat below observed levels, as shown for Lake Superior, may result in a bias toward overestimating the benefits of proposed regulation plans. Lack of economic data prevented an evaluation of the bias possibility, but it represents a question which needs further investigation.

One of the more serious concerns of the data base is related to the background climatic characteristics of the years represented in the sample interval 1900-1967. A large number of years represented in the data base utilized by the International Great Lakes Levels Board to evaluate alternative lake level management plans were characterized by relatively warm and relatively dry climatic conditions which may occur less frequently in the next few decades. The University research indicated that differences in decadal scale and long-term means of lake levels were primarily related to climatic factors rather than to specific management plans. Although some proposed regulation plans can produce relatively significant and immediate impacts on levels of specific lakes, such alternatives are prevented because of water needs of power and navigation interest groups and because of negative hydrologic impacts on downstream lake systems. The artificial constraints on regulation plans therefore result in climate being the dominant factor in the temporal variation of lake levels.

It is especially important to recognize the role of climate in lake level fluctuations because studies of the historical record of climate in the Great Lakes region indicate that return frequencies of many characteristics of climate which dominated the first half of the twentieth century are not representative of climate recurrence frequencies determined from longer time scales. The unusualness of the particular array of climatic conditions which dominated the data base 1900-1967 was implied in the results of ten simulations generated by the IGLLB to estimate the expected range of possible future water supplies. These simulations of arrays of supply conditions, each spanning a 68-year period, indicated that in approximately 9 out of 10 instances, for both Lake Superior and Lakes Michigan and Huron, the calculated mean levels under both the BOC and management Plan SO-901 were higher than those mean levels generated using the recorded water supply data for the 1900-1967 base period. Although proposed management schemes, such as Plan SO-901, can produce small net benefits to the entire Great Lakes system under the most constraining climatic condition represented in the simulated supplies, costs and benefits are unequally distributed among the lakes of the system. The discrepancy seems to be most severe during periods when net basin supplies are above the average of the 1900-1967 norm. Because of a reasonably good chance that net basin supply conditions of the 1900-1967 base period may be biased toward low magnitudes, it is necessary that qualifications be attached to benefits derived from management plans which have been evaluated in relation to the 1900-1967 data base.

B. Impacts of Management Plans

Studies of the impacts of regulating lake levels were primarily restricted to Plan SO-901 because of the importance given to it by the International Great Lakes Levels Board. Less detailed hydrologic evaluations were made for alternative management plans which included: Mod 7 and Mod 8 of Plan SO-901, Plan SEO-42P, and Plan SEO-17P.

Plan SO-901. A primary objective of Plan SO-901 is to maintain the levels of Lakes Superior, Michigan, and Huron as close as possible to their respective long-term mean levels. The plan is similar in design to the Basis-of-Comparison regulations except for the rule which governs the discharge from Lake Superior. In Plan SO-901, discharge from Lake Superior is determined from the levels of both Lake Superior and Lakes Michigan and Huron. Discharge from Lake Superior for the BOC regulation plan depended only on the level of Lake Superior. The present evaluation analyzed specific hydrologic impacts resulting from the attempt to balance lake levels around their long-term means.

Analyses indicated that Plan SO-901 was successful in preserving the mean seasonal variations in lake levels as called for in the regulation plans. However, Plan SO-901 imposes constraints upon the natural variations of levels. The net effect of the plan is to slightly increase the standard deviations of Lake Superior levels and to slightly decrease the monthly standard deviations of Lake Michigan levels. The influence of Plan SO-901 on the standard deviations of levels, relative to the BOC base, was reflected in a greater frequency of both higher and lower levels on Lake Superior. Although a greater frequency of high stages can definitely be attributed to Plan SO-901, the absolute number of occurrences of damaging levels appears to be small. An analysis of Lake Superior levels for all months for the period 1900-1973 revealed that the number of times the mean monthly stage of 601.4 feet was exceeded (a stage which served as a crude benchmark for estimating damaging lake levels),* increases from 27 for the BOC plan to 46 for Plan SO-901 (Table 1). An increase of only 19 is relatively small for such a long record, but it is significant that most of the increases were associated with the four months, August through November, the period normally associated with the highest damages on Lake Superior. The influence of Plan SO-901 on the standard deviations of levels was reflected in a decreased frequency of both extreme high and low levels on Lakes Michigan and Huron. The analysis of Lake Michigan and Lake Huron levels for all months for the period 1900-1973 revealed that the number of times the mean monthly stage of 579.6 feet was exceeded,* decreased from a total of 68 for the BOC plan to only 44 occurrences under Plan SO-901. Most of the adjustments were restricted to the normal high stage months of June through September. It is difficult to evaluate the hydrologic significance of these modest changes, but it should be noted that relatively infrequent events can account for a very large portion of the total damages of an extended time period.

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* Mr. B. DeCooke of the U.S. Army Corps of Engineers, Detroit office, was asked in a personal communication to estimate the magnitudes of average monthly lake levels for Lakes Superior, Michigan, and Huron above which complaints of damages to shore property became frequent. He estimated that a reasonable approximation would be about 601.4 feet for Lake Superior and 579.6 feet for Lakes Michigan and Huron. Although these levels represent a perception that is not based upon hard data, the University research team elected to utilize these levels as crude indices from which to judge relative hydrologic impacts of proposed management plans.

TABLE 1 COMPARISON OF EFFECTS OF MANAGEMENT PLANS FOR 1900-1973 (FEET ABOVE SEA LEVEL—IGLD 1955)

EFFECTS OF REGULATION PLANS ON LAKE SUPERIOR (IN FEET)

Plan	Mean	Standard Deviation	Number of Monthly Means: <600.00	>601.40	>601.60	Total Range
BOC	600.41	.65	214	27	16	3.55
SO-901	600.46	.67	208	46	17	3.20
SEO-42P	600.41	.67	223	37	16	3.19
Mod 7	599.99	.86	445	18	11	4.19
Mod 8	599.76	.89	516	12	9	4.34

EFFECTS OF REGULATION PLANS ON LAKES MICHIGAN-HURON (IN FEET)

Plan	Mean	Standard Deviation	Number of Monthly Means: <576.80	>579.60	>580.00	Total Range
BOC	578.04	1.19	131	68	28	6.11
SO-901	578.04	1.07	109	44	17	5.32
SEO-42P	577.94	1.06	129	30	14	5.28
Mod 7	578.05	.99	87	29	12	4.84
Mod 8	578.05	.98	82	29	10	4.80

Source: University of Wisconsin-Madison 1975.

The modest effects of Plan SO-901 on the standard deviations of lake levels are also apparent in slightly altered frequencies of levels below the normal low water datums. For example, it was found that the number of monthly mean lake levels less than the low water datum of 600.0 feet for Lake Superior was 214 for the BOC and 208 for Plan SO-901. Comparable figures for a datum of 576.8 feet on Lakes Michigan and Huron were 131 for the BOC and 109 for Plan SO-901 (Table 1). Although these data suggest that extreme lows are reduced on both lake systems, the results of present lake level probability studies revealed that Plan SO-901 increased the frequency of low levels in the interval above the low water datum, but below the mean level. Hence, Plan SO-901 has a general tendency, related to the between lake balancing process, to cause Lake Superior to be somewhat higher than it normally would be under the BOC plan. Also, because of balancing, Plan SO-901 usually results in Lakes Michigan and Huron being slightly higher than expected BOC levels during periods of below normal net basin supplies and slightly lower than expected BOC levels during periods of above normal net basin supplies. The relatively modest effects of Plan SO-901 are explained by the flow limitations in the St. Marys River between Lake Superior and Lakes Michigan and Huron. The discharge of the St. Marys River is restricted during winter months to flows which do not exceed 85,000 cfs because larger flows have been known to produce flooding in association with ice jams. During the months of January through April, when ice jamming can be a particular problem, Plan SO-901 would on the average be implemented only about 30% of the time.

Although the St. Marys discharge can be increased to a maximum of about 125,000 cfs during summer months, high net basin supplies of spring and summer usually exceed the maximum channel capacity. As a consequence, even during late summer and early fall Plan SO-901 can be operated at capacity only 50 to 60% of the time. It was estimated that the average time of operation for Plan SO-901 for the entire period 1900-1973 would have been 41%.

In summary, the differences between lake levels under the BOC regulation plan and Plan SO-901 are relatively modest. Principal reasons for the modest effects are the severe limitations on discharge magnitudes created by the capacity of the St. Marys River and by available storage on downstream lakes. The net result of the restrictions on the Plan SO-901 leaves climatic influences on net basin supplies as the primary cause of water level problems on Lakes Superior, Michigan, and Huron.

Plan SO-901 Mod 7 and Mod 8. The Mod plans represent attempts to improve benefits on the lake system by increasing the range of water levels on Lake Superior. Since the increase in the range is to be implemented by lowering the limits of permissible minimum levels on Lake Superior, the plans require dredging to protect navigation interests in Lake Superior channels and harbors including portions of the St. Marys River. It may be recalled from Part I of this paper that the general effects of the Mod plans involve lowering the mean level of Lake Superior by 0.5 to 0.8 feet below the mean levels of the general Plan SO-901. At the same time, the standard deviation of Lake Superior levels is increased by approximately 30%. Relative to Plan SO-901, the Mod plans generally preserve the mean level of Lakes Michigan and Huron, but only slightly reduce the variability of levels.

The range of lake levels on Lake Superior increases from 3.20 feet under the general Plan SO-901 to 4.19 and 4.34 feet, respectively, for the Mod plans of SO-901. On Lakes Michigan and Huron the range of lake levels decreases from 5.32 feet under the general Plan SO-901 to 4.84 and 4.80 feet, respectively, for the Mod plans of SO-901 (Table 1). Both Mod plans appear to have a significant impact on the reduction in damaging water levels where threshold levels of damage are recognized to be 601.4 feet on Lake Superior and 579.6 feet on Lakes Michigan and Huron as described in the previous section on the general Plan SO-901. For example, on Lake Superior, Plan SO-901 produced 46 occurrences in which average monthly levels would exceed 601.4 feet, but Mods 7 and 8 reduce these occurrences to 18 and 12, respectively. On Lakes Michigan and Huron, Plan SO-901 produced 44 occurrences in which average monthly levels would exceed 579.6 feet, but Mods 7 and 8 reduce these occurrences to 29 in both instances. The Mod plans also have a very significant impact on the relative number of occurrences of lake levels below the normal low water datum elevations. For example, on Lake Superior, average monthly water levels for the period 1900-1973 drop below the low water datum of 600.0 feet 208 times under Plan SO-901, but under Mods 7 and 8 the average monthly water levels would drop below the low water datum 445 and 516 times, respectively. It is the relative high frequencies of low water levels which necessitate the dredging in Lake Superior channels and harbors and portions of the St. Marys River. On Lakes Michigan and Huron, average monthly water levels for the period 1900-1973 drop below the low water datum of 576.8 feet 109 times under Plan SO-901, but under Mods 7 and 8 the average monthly water levels would drop below the low water datum 87 and 82 times, respectively.

Because Mods 7 and 8 do not involve significant increases of the channel capacity of the St. Marys River, and because the constraints of the release rule are essentially the same as for the general Plan SO-901, the percentage of time during which each of the Mod plans is operative during the historical record 1900-1973 are not significantly different from the operative time for Plan SO-901. For example, Plan SO-901 was estimated to be operative approximately 41% of the time with other times being constrained by seasonal flow limitations in the St. Marys River. Comparable operative times for Mod 7 and Mod 8 are 43% and 46%, respectively.

In summary, a comparison of the effects of either Plan SO-901 or the BOC plan against the effects of Mods 7 and 8 of Plan SO-901 reveals that both Mods 7 and 8 have substantial impacts on Lake Superior mean monthly levels as well as on the variances of levels about the means. A similar comparison for Lakes Michigan and Huron reveals that Mods 7 and 8 of Plan SO-901 primarily reduce the total range of mean monthly levels. Both Mod plans substantially reduce the frequency of damaging water levels on Lakes Superior, Michigan, and Huron. The benefits of reduced occurrences of high lake levels are essentially neutralized by the necessity for dredging in Lake Superior channels and harbors and in portions of the St. Marys River to offset the impact of the Mod plans on drastically increasing the frequency of water levels below the current low water datum on Lake Superior.

Plans SEO-42P and SEO-17P. The SEO plans involve the coordinated regulation of Lakes Superior, Erie, and Ontario. The plans are based upon findings that favorable benefits could be achieved by increasing the outlet capacity of Lake Erie to carry increased discharges during periods of excessive supplies. Plan SEO-42P calls for an additional outflow of 8,000 cfs, whereas SEO-17P would permit the passage of an additional 17,500 cfs above the normal base. Lakes Superior and Ontario would continue to be regulated according to the conditions of Plan SO-901.

Under the SEO plans Lake Superior would experience approximately the same variations in mean monthly levels as expected under Plan SO-901. The long-term mean level of Lakes Michigan and Huron would be reduced by approximately 0.1 feet by the SEO plans relative to Plan SO-901 because of the effect of the increased Niagara River outlet capacity to lower Lake Erie. The long-term mean level of Lake Erie would be approximately 0.3 feet lower under the SEO plans than it would be under Plan SO-901. The SEO plans, relative to Plan SO-901, have little or no effect on the range of levels on Lakes Superior, Michigan, and Huron. However, the enlarged capacity of the Niagara River to discharge water from Lake Erie increases the range of mean monthly levels on Lake Ontario.

Plan SEO-42P appears to be relatively comparable to Plan SO-901 in producing damaging high water levels on Lakes Superior, Michigan, and Huron. For example, it may be recalled that for Lake Superior, Plan SO-901 produced 46 occurrences in which average monthly levels would exceed 601.4 feet during the historical period 1900-1973. The comparable figure for Plan SEO-42P is 37 occurrences which is substantially larger than 18 and 12 occurrences for Mods 7 and 8 of Plan SO-901.

The reader may also recall that the average monthly level of 601.4 feet was exceeded 27 times during the historical period 1900-1973 for the BOC mode of regulation. On Lakes Michigan and Huron, Plan SEO-42P produced 30 occurrences of average monthly water levels above the critical stage of 579.6 feet. The 30 occurrences compare closely to the 29 occurrences of damaging water levels produced during the historical period 1900-1973 by Mods 7 and 8 regulatory plans. The reader may recall that the general Plan SO-901 produced 44 instances of mean monthly water levels above the critical threshold of 579.6 feet, and the comparable figure for the BOC regulation plan was 68 occurrences. The differing responses of the two lake systems to management plans reflect the independence of Lake Superior as determined by the controls in the St. Marys River. Lakes Michigan and Huron, on the other hand, experience some upstream effects from the quicker lowering of Lake Erie following periods of excessive net basin supplies.

The effects of Plan SEO-42P to produce average monthly water levels below the low water datum on Lake Superior appears to be somewhat comparable to the effects of Plan SO-901. For example, SEO-42P results in 223 instances in which average monthly levels drop below the low water datum of 600.0 feet on Lake Superior. Comparable statistics for the other regulation plans are 214 for BOC, 208 for SO-901, 445 for SO-901 Mod 7, and 516 for SO-901 Mod 8. On Lakes Michigan and Huron the number of instances of average monthly water levels falling below the low water datum of 576.8 feet during the 1900-1973 period is 129, which is larger than the 109, 87, and 82 occurrences that would be expected, respectively, with Plan SO-901 and its Mods 7 and 8. For the same period, BOC would be expected to be associated with 131 instances in which the average monthly water levels would drop below the low water datum (Table 1).

The University group did not analyze the effects of Plan SEO-17P, a later revision of Plan SEO-42P, to determine its effects on damaging water levels as defined above. However, inspection of data provided by the U.S. Army Corps of Engineers indicates that the relative effects of the plan on Lakes Superior, Michigan, and Huron would not be significantly different from the effects produced by Plan SEO-42P (U.S. Army Corps of Engineers 1974). In comparison to SEO-42P, SEO-17P has the greatest impact on Lake Ontario where it lowers the maximum and raises the minimum levels (Table 25).

In summary, the SEO plans slightly reduce the long-term mean levels of Lakes Superior, Michigan, and Huron when compared to Plan SO-901. A similar comparison indicates that Plans SO-901, SEO-42P, and SEO-17P have virtually the same effect on the range of levels for Lakes Superior, Michigan, and Huron. The SEO plans are estimated to produce the greatest relative benefits on Lakes Michigan and Huron and on Lake Erie.

C. Diversions

There are three principal areas of diversions which have significant impacts on the water levels of the Great Lakes. The three areas are represented by a current average input to Lake Superior of 5,000 cfs from the Albany River basin, an average outflow of 3,200 cfs at Chicago from Lake Michigan into the Mississippi River basin, and a diversion of about 7,000 cfs from Lake Erie to Lake Ontario via the Welland Canal. The IGLLB Main Report (1973, pp. 44-45) indicates that the Albany diversion has no effect on the average level of Lake Superior because of compensating adjustments in the discharge of the St. Marys River. However, the IGLLB estimates that the ultimate effect of the Albany diversion is to increase the level of Lakes Michigan and Huron by 0.37 feet and Lake Erie by 0.23 feet. The Chicago diversion reduces the level of Lakes Michigan and Huron by 0.23 feet and Lake Erie by 0.14 feet. The Welland Canal lowers the level of Lakes Michigan and Huron by 0.10 feet and Lake Erie by 0.32 feet. Therefore, the net effects of diversions on the Great Lakes average water levels will be nil on Lake Superior, an increase of 0.04 feet on Lakes Michigan and Huron, and a reduction of 0.23 feet on Lake Erie.

The University research team did not have time to evaluate the possible effects of a sophisticated system in which lake diversions might be closely coordinated with variations in net basin supplies. Because the diversions have traditionally been viewed more in relation to national and regional interests as opposed to component parts of a total Great Lakes system, temporal adjustments of discharges in the diversions have been relatively conservative. It is apparent, for example, that increasing the Chicago diversion up to 10,000 cfs over a period of several years would result in an ultimate lowering of Lakes Michigan and Huron by 0.6 to 0.7 feet. The Chicago diversion has transmitted discharges of 10,000 cfs in the past, but in recent years the water release has averaged only 3,200 cfs.

In summary, knowledge concerning the possible benefits of diversions which would be closely tied to variations in net basin supplies is relatively limited. Since current diversions have significant impacts on Great Lakes water levels, high priority should be given to a study of the possible benefits of highly flexible diversion rates.

D. Summary

Within the past fifteen years the Great Lakes have experienced both extremely high and extremely low net basin supplies. The variations in supplies were associated with deviations of lake levels representing major departures from long-term mean elevations. Considerable controversy has evolved concerning the relative contributions of natural and man-related components of net basin supplies which influence these levels. The research summarized in this paper evaluates the relative impacts of several management schemes which have been developed under the auspices of the International Great Lakes Levels Board as possible alternatives to alleviate water level problems during periods of extreme high or low supplies.

One of the more serious concerns of the data base utilized by the International Great Lakes Levels Board to evaluate alternative lake level management plans is related to the background climatic characteristics of the years represented in the sample interval 1900-1967. A large number of years represented in the data base were characterized by relatively warm and relatively dry climatic conditions which may occur less frequently in the next few decades. Studies of the historical record of climate in the Great Lakes region indicate that return frequencies of many characteristics of climate which dominated the first half of the twentieth century are not representative of climate recurrence frequencies determined from longer time scales. The University research indicated that differences in decadal scale and longer-term means of lake levels were primarily related to climatic factors rather than to specific management plans.

The research effort confirmed that many of the management alternatives proposed by the International Great Lakes Levels Board (IGLLB) have the potential to produce relatively immediate and significant impacts on Great Lakes water levels. However, such actions are prevented because of negative impacts to various interest groups on the lakes, e.g., shore property, navigation, and power. It was found that the most favored lake level management plans could only be practiced at full capacity on the average of 40% to 60% of the time because of limitations set by negative hydrologic impacts elsewhere in the Great Lakes system. In some winter months when ice jamming and related flooding are serious concerns, the percent of time that a plan could be practiced at full capacity drops to about 30%. As a consequence of the limitations on management alternatives, climate remains as the principal cause of the extreme deviations of lake levels from their long-term average elevations.

The results of the University research revealed that the management plans proposed by the International Great Lakes Levels Board preserved, in general, the normal pattern of seasonal variations of lake levels. Plan SO-901, which has been offered as an alternative that would provide slight net benefits for a relatively modest investment of capital for implementation, has the general tendency to cause Lake Superior to be somewhat higher than it normally would be relative to the regulation plan in effect from 1955 to 1973 which serves as a Basis-of-Comparison. Plan SO-901 also has the general tendency to cause Lakes Michigan and Huron to be slightly above BOC levels during periods of below normal net basin supplies and slightly below expected BOC levels during periods of above normal net basin supplies. The BOC data represent lake levels simulated by routing net basin supplies of the historical period 1900-1967 through the Great Lakes system under conditions of constant regulatory rules. Specific characteristics of the BOC data base differ somewhat depending upon whether a management scheme being assessed involves either structural or nonstructural regulatory controls. Therefore, it is important to recognize that the estimates of the effects of management plans are judged against controlled BOC benchmarks of lake levels rather than lake levels which would have resulted were there no controls of any type. The general effect of the September 1955 Modified Rule of 1949, which is the principal part of the BOC regulatory scheme for Lake Superior, has probably increased the overall long-term mean level of Lake Superior by approximately 0.34 feet above the level expected for natural conditions. On Lakes Michigan and Huron the effects of the BOC regulatory scheme, operating under restrictions of 1962 outlet conditions for Lake Huron, appear to result in the long-term mean levels being 0.61 feet lower than the level expected for natural conditions.

Mod 7 and Mod 8 of Plan SO-901 represent two attempts to improve benefits on the lake system by adjusting Plan SO-901 through increasing the range of water levels on Lake Superior. In general, the Mod plans involve lowering the mean level of Lake Superior by 0.5 to 0.8 feet below the mean levels of the general Plan SO-901. At the same time, the standard deviation of Lake Superior levels is increased by approximately 30%. Relative to Plan SO-901, the Mod plans generally preserve the mean level of Lakes Michigan and Huron, but slightly reduce the standard deviation of levels. Both Mod plans result in a substantial reduction in the frequency of damaging water levels on Lakes Superior, Michigan, and Huron. The benefits of reduced occurrences of high lake levels are substantially neutralized by the necessity for dredging in Lake Superior channels and harbors and in portions of the St. Mary's River to offset the impact of the Mod plans to drastically increase the frequency of water levels below the current low water datum on Lake Superior.

The SEO plans involve the coordinated regulation of Lakes Superior, Erie, and Ontario. Under these plans Lake Superior is regulated according to the general guidelines defined for Plan SO-901, and the outlet capacity of Lake Erie is increased to permit the discharge of additional water during periods of excessive net basin supplies. Because Lake Superior is regulated relatively similarly under both SEO and SO-901 plans, little difference is apparent concerning characteristics of lake levels between the two management schemes. However, the long-term mean level of Lakes Michigan and Huron would be reduced by approximately 0.1 feet by the SEO plans relative to Plan SO-901 because of the lowering of Lake Erie produced by an increased outflow capacity in the Niagara River. The long-term mean level of Lake Erie would be approximately 0.3 feet lower under the SEO plans than it would be under Plan SO-901.

It can be concluded that the relative impacts of the various proposed management schemes represent relatively small net changes in the long-term averages of lake levels. The most significant impacts are related to lake levels which represent large deviations from long-term average levels. For Lake Superior, Plans SO-901, SEO-42P, and SEO-17P would, relative to the BOC impact, increase the frequency of lake levels which have the potential to produce high magnitude shore property damages; Mods 7 and 8 of Plan SO-901 would decrease the frequency of those high lake levels on Lake Superior. Unfortunately, Mods 7 and 8 would, relative to the BOC impact, more than double the number of instances in which Lake Superior average monthly lake levels would drop below the mean low water datum and would necessitate a dredging of Lake Superior harbors and channels. For Lakes Michigan and Huron, all proposed management plans described in this paper would, relative to the BOC impact, decrease the incidence of high magnitude average monthly lake levels which have the potential to produce extensive shore property damages. The two SEO plans and Mods 7 and 8 of Plan SO-901 are relatively comparable in reducing the number of occurrences of the high average monthly lake levels and all four are significantly better than the general Plan SO-901 in that capacity. Although all of the here described proposed management plans for Lakes Michigan and Huron reduce the number of instances in which the average monthly lake levels would drop below the mean low water datum, Mods 7 and 8 of Plan SO-901 are significantly more effective than Plan SO-901 or the SEO plans.

Although Mods 7 and 8 of Plan SO-901 appear to represent the most effective plans for regulation of lake levels, their benefits are somewhat offset by the costs of dredging to prevent serious impediments to navigation interests. Of the several proposed management plans, SO-901 appears to provide the most benefits for the least investment. It is very possible that significant improvements to Plan SO-901 could be achieved by implementing a greater range of variability in the diversions of water into Lake Superior from the Albany River basin, out of Lake Michigan at the Chicago Sanitary and Ship Canal, and out of Lake Erie at the Welland Canal. A sophisticated system in which lake diversions might be closely coordinated with variations in net basin supplies to the lakes needs further investigation.

II. HYDROLOGIC DATA BASE—THE BASIS-OF-COMPARISON

Introduction

The data base against which the IGLLB judged the proposed management plans represents neither unregulated 'natural' lake levels nor actual recorded levels on the lakes. Because several different regulation plans have affected the recorded levels on the lakes, it was necessary to adjust the recorded levels in accordance with some standard base of regulation. Standardization was therefore accomplished by routing net basin supplies of the historical period 1900-1967 through the Great Lakes under a set of uniform regulatory controls for the entire period.

Standardization of the data over the base period 1900-1967 has introduced two principal problems of concern. First, use of the standardized data as a Basis-of-Comparison (BOC) to judge other management plans implies that estimated effects of the various proposed management plans do not represent differences relative to natural conditions. Second, the base period 1900-1967 was dominated by climate conditions favoring net basin supplies of lower magnitude than might be expected for the immediate future.

A. BOC Levels vs Natural Levels

The BOC is a simulated sequence of levels for the Great Lakes. These levels serve as a reference from which to compare alternative regulation plans. The BOC data are mostly based upon regulation rules, diversions, and channel configurations that were in effect from 1962-1973, except for some simulations which are designed to test the effects of structural controls. In the latter, lake outlet conditions of some earlier years are assumed. The BOC data base was not intended to closely reconstruct the historical record of lake levels, but rather it was intended to demonstrate the amount of expected lake level variation in response to natural factors affecting net basin supplies under conditions of a constant regulation plan.

It is difficult to reconstruct natural conditions of lake level response to net basin supplies because pre-1900 relationships between lake stages and discharges are poorly understood. However, given certain assumptions about outlet conditions, the International Great Lakes Levels Board (IGLLB) attempted to estimate natural stage/discharge relationships. For example, Table 2 shows that when using unregulated 1887 outlet conditions for Lake Superior, the overall mean level of the lake is .34 feet lower than under BOC (600.04 vs. 600.38) for supplies of the 1900-1967 period. It also shows that when 1962 outlet conditions are assumed in the BOC, the levels of Lakes Michigan and Huron are .61 feet lower than levels generated utilizing the unregulated 1887 conditions. Thus, the 1955 plan, as well as the preceding plans, tended to increase the level of Lake Superior and decrease the level of Lakes Michigan-Huron as compared to what would happen if more natural outlet conditions are assumed.

This conclusion is not surprising when looking at the history of Lake Superior regulation and the goals behind past regulation plans. The 1914 Orders of Approval called for the regulation of Lake Superior "as near as may be" between 600.5 and 602 feet (converted to IGLD, 1955) and in such a manner as not to interfere with navigation. Since the historical recorded mean level for all months combined for Lake Superior from 1860-1972 is 600.39 feet, the plans should have been designed to raise the level of Lake Superior, as required by the 1914 specified range of stage. This range was intially fixed by the War Department in 1903 by a permit issued to the Michigan Power Company. It should also be understood that the power companies, who applied to the International Joint Commission (IJC) for permission to obstruct the Lake Superior outflows, benefit most when water is held back during periods of above average supply in order that more water may be available during critical low flow periods.

The objective of the plans of regulation for Lake Superior have traditionally considered primarily the power and navigation interests. Rule P-5, adopted in 1941, was designed for the purpose of increasing minimum flow rates for power. This was replaced by the "Rule of 1949" in consideration of the increased supplies from the 1940 Canadian diversion into Lake Superior. The Rule of 1949 was replaced by the September 1955 Modified Rule of 1949 for the purpose of decreasing the frequency of occurrence of low outflows from Lake Superior in the range where it is necessary to curtail the amount of water used for power generation (Wisconsin v. Illinois, 388, U.S. 426, 1968).

In summary, the BOC data bases appear to generate lake levels biased in favor of navigation and power interests. These biases in the data make comparison of proposed future lake level management alternatives versus uncontrolled natural conditions difficult. It would be useful to reconstruct a totally unregulated lake system in order to better evaluate the effects of controls on the natural system of the Great Lakes.

TABLE 2 CALCULATED EFFECTS OF LAKE REGULATION SUMMARY OF RANGES OF STAGE IN FEET AND OUTFLOW IN THOUSANDS OF CUBIC FEET PER SECOND—1900-1967

	Regulated*		Unregulated**	
LAKE SUPERIOR REGULATION	Stage	Outflow	Stage	Outflow
Lake Superior				
Mean	600.38	77	600.04	77
Maximum	601.91	123	602.02	119
Minimum	598.36	55	598.02	39
Range	3.55	68	4.00	80
Lakes Michigan-Huron***				
Mean	578.54	183	578.56	183
Maximum	581.50	233	581.28	229
Minimum	575.74	107	575.70	110
Range	5.76	126	5.58	119
Lake Erie				
Mean	570.60	204	570.61	204
Maximum	573.01	258	572.88	255
Minimum	567.95	149	567.85	147
Range	5.06	109	5.03	108
Lake Ontario				
Mean	244.53	238	244.52	238
Maximum	246.95	310	246.94	310
Minimum	241.31	176	241.19	188
Range	5.64	134	5.75	122
LAKE ONTARIO REGULATION	Regulated*		Unregulated	
Lake Ontario				
Mean	244.53	238	244.54	238
Maximum	246.95	310	247.58	304
Minimum	241.31	176	241.53	168
Range	5.64	134	6.05	136

Source: IGLLB 1973, Main Report, p. 48.

* For assumed system conditions, see pages 3-4.

** 1887 Lake Superior outlet conditions and using average computed ice retardation.

*** 1933 outlet conditions. (To estimate Lakes Michigan-Huron level under 1962 outlet conditions subtract .59 feet.)

B. The BOC and Net Basin Supplies (1900-1967)

Although the International Great Lakes Levels Board (IGLLB) assumed that the 1900-1967 period provided a data base which represented the possible range of conditions affecting the range of net basin supplies, this assumption may be incorrect. This concern is supported by the fact that: (a) statistically simulated sequences of lake levels frequently had mean magnitudes which exceeded that of the 1900-1967 base, (b) record high supplies have occurred since 1967, and (c) studies of the historical record of climate for the Great Lakes region indicate that climate conditions which dominated the years 1900-1967 may have been biased in favor of producing lower magnitudes of net basin supplies than might be expected in the immediate future. Because of the strong role of climate in the determination of net basin supplies, the general climatic conditions of the base period 1900-1967 and the implications of those climatic conditions are examined in somewhat greater detail in the following section of this report.

III. CLIMATIC INFLUENCE ON WATER LEVELS OF LAKES SUPERIOR, MICHIGAN, AND HURON

Introduction

Climate is the driving force in any hydrologic cycle. In this regard it is of special interest that the principal data base for Plan SO-901 and its alternatives are largely based upon data derived from the period 1900 to 1967. The climate of the period 1900 to 1967 is considered by many scientists to be somewhat biased toward relatively warm and relatively dry conditions. Investigations, now underway at the University of Wisconsin and elsewhere, suggest that climate systems which dominated the first half of the 1900s are no longer in control. The time of adjustment in the return frequencies of circulation regimes, which were once dominant, varies from region to region, but 1950 appears to be a reasonable approximation for the time of change in the Great Lakes region. Changes in return frequencies of circulation regimes may be expected to affect many of the factors controlling net basin supply to the Great Lakes.

A. Evidence of Historical Changes of Climate

Examinations of long historical records of climate reveal that climate has varied considerably from what is currently perceived as "normal." Some climate departures have lasted for long periods of time while other departures are only represented by persistence of climate characteristics on the scale of a few years.

In the Upper Mississippi Valley and Great Lakes region the climate of the last 150 years may be divided into three episodes. The first episode extended from the middle of the last century and continued until about 1920. It was characterized by climate conditions which were relatively cool and wet compared to the following period which extended to about 1950. The second period, which represents much base period data of the IJC regulation plans, was characterized by relatively frequent strong westerly flow in the upper atmosphere which was responsible for the period being relatively warm and relatively dry. The third period, beginning about 1950, extends to the present and appears to represent a return to circulation regimes which were more frequent in the first period. For example, the strong westerly flow in the upper atmosphere, which was characteristic of the middle period, has been replaced by regimes of circulation having a strong north/south component. The recent circulation shifts have resulted in the climate again becoming somewhat cooler and wetter.

Studies by Wahl (1968) and Wahl and Lawson (1970) of the historical records of climates of the early and middle 1800s reveal that the 30-year span from 1931 to 1960, a period which has frequently been utilized to describe climatic averages, was the warmest 30-year period in the Northern Hemisphere in the last 100 to 200 years. The relatively warm episode of the early twentieth century may represent only a brief fluctuation from somewhat cooler climatic conditions which have characterized the last three to four centuries (Wahl and Lawson 1970, p. 264). Bryson (1974, p. 754) has also noted the unusual character of the climate of the 1931-1960 base period and he reported that: "there appears to be nothing like it in the past 100 years."

Maps reconstructing climate patterns of the 1850s and 1860s by Wahl and Lawson (1970) show seasonal temperature and precipitation patterns which are significantly different from those of the 1931-1960 period. Their maps indicate that the Midwest was from 1 to 3 degrees (F) cooler in the mid-1800s than in the 1931 to 1960 period, the greatest difference being in early fall. Precipitation in the Midwest was greater than the 1931 to 1960 base period in most seasons during the mid-1800s. Inspection of Wahl and Lawson's data revealed that summer precipitation of the mid-1800s was approximately equal to the 1931 to 1960 base data over the Michigan-Huron basin, but was about 10% below the base data for the western half of the Lake Superior basin. On the average, annual precipitation appears to have been about 10 to 20% greater than the 1931 to 1960 base over much of the Great Lakes basin, the greatest difference being during the winter season which represented a 40% difference. The climate of the post 1931 to 1960 period has been examined by Kalnicky (1974), who found that regional temperature patterns over the United States for the period 1961 to 1970 had a marked similarity to those of the mid-nineteenth century. Knox et al. (1975) have examined variations in the return frequencies of dominant upper atmospheric circulation regimes for the period 1925 through 1969. They found that many of the circulation regimes which dominated the early years of the record were no longer dominant in the latter years of the record. The findings of the Knox study supported the findings of previous studies that 1950 is a reasonable approximation for a date of climate adjustment in the Great Lakes region. Knox et al. found that adjustments of climate circulation characteristics have occurred for the warm season months of May through September. Many of the adjustments were found to involve a decrease in the importance of circulation regimes characterized by a strong westerly component in favor of circulation regimes having a strong north/south component. The departure from circulation regimes which dominated months of pre-1950 years became more strongly apparent during the decade of the 1960s. The 1960s were observed to be especially characterized by high year-to-year variation in the dominant circulation regimes. The recent adjustment in upper atmospheric circulation regimes is responsible for the frequent occurrences of high net basin supplies and related high lake levels of the past few years. Under the limitations of present forecasting technology, it is impossible to accurately predict how long the present period of high supplies might last. However, it is significant to note Kutzbach's observation (cited in Bryson et al. 1974, p. 23) that: "the record of the past millennium shows that high latitude cooling, such as that which characterized the last twenty years, has never reversed in less than 40 years, or returned to the original state in less than 70 years." The cooler period of the past two decades has been associated with occurrences of very high magnitude lake levels as represented by the early 1950s and again in the early 1970s. The net basin supplies of the last few years have reached record high magnitudes as described by the International Great Lakes Levels Board (IGLLB 1973, Main Report, pp. 233-234):

> Since 1967 the precipitation on the Great Lakes basin has averaged 8% more than the 31.4 inches per year averaged over the study period 1900-1967.
>
> In 1973 Lakes Michigan and Huron reached their highest levels since 1886, and Lakes St. Clair and Erie exceeded any previously recorded levels.
>
> The recent net basin supplies to the various lakes were from 27% to 119% above the 68-year (1900-1967) period averages; the net total supplies were from 25% to 47% greater.

The International Great Lakes Levels Board recognizes that long-term fluctuations in lake levels occur in response to persistent low or high water supply conditions within the Great Lakes basin, but they concluded (IGLLB 1973, Main Report, p. 244) that:

> . . . there are no regular, predictable cycles such as one might expect.
>
> The intervals between periods of high and low levels and the length of such periods vary widely and erratically over a number of years.
>
> . . . the data have not permitted the identification of any current long-term climatic trend in the Great Lakes region.

While it is true that "regular cycles" of long-term fluctuations of net basin supplies and lake levels do not appear in the record, it is important to recognize that departures of net basin supplies from the average are not randomly distributed in time. In other words, long historical records reveal evidence of persistence of both above normal and below normal supplies. It is especially important to note that a large portion of the data base utilized by the International Joint Commission for evaluating lake level regulation plans is characterized by relatively warm and dry climatic conditions which may occur less frequently in the next few decades.

B. Economic Impact of Climate Variations

Damage estimates determined for the 1968-1973 period by the International Great Lakes Levels Board (IGLLB 1973, Main Report, p. 235) approximated the economic significance of the recent period of high net basin supplies in comparison to the long-term 1900-1967 average. The comparative analyses of the IGLLB indicated that under Plan SO-901 for the 1900-1967 net basin supplies, Lake Superior shores would experience an average annual loss of approximately $100,000 and Lakes Michigan and Huron shores would experience an average annual net benefit of approximately $900,000. However, the Levels Board data reveal (IGLLB 1973, Main Report, p. 235) that under conditions representative of the high supplies of the 1968-1973 period, Plan SO-901 would result in an average annual loss of approximately $1,900,000 on Lake Superior shores and a net benefit of approximately $1,600,000 on the shores of Lakes Michigan and Huron. In other words, during periods of above normal net basin supplies as occurred from 1968-1973, the damages on Lake Superior shores increase out of proportion to the benefits achieved on Lakes Michigan and Huron shores.

The IGLLB data suggests that Plan SO-901 would produce a net loss of approximately $300,000 annually for the combined Lakes Superior, Michigan, and Huron shores during periods of high supply as occurred from 1968-1973. Although the Levels Board indicate that net benefits of approximately $800,000 would result from Plan SO-901 during such periods of high supply, when all of the Great Lakes are considered simultaneously, the fact remains that Lake Superior absorbs tremendous damages at the expense of downstream interests.

The hydrologic evaluation by the IGLLB of lake levels for different periods of climate conditions indicated that the recent period of high net basin supplies (1968-1973), in comparison to the 1900-1967 base period, resulted in an increase of mean lake levels of approximately 0.35 feet on Lake Superior and an increase of about 1.08 feet on Lakes Michigan and Huron for the current regulation plans (IGLLB 1973, Main Report, p. 235). For Plan SO-901 the respective increases for the high net basin supply period 1968-1973 are 0.56 feet for Lake Superior and 0.97 feet for Lakes Michigan and Huron. These data do suggest that relatively small variations in lake levels result in relatively large net losses or net benefits.

Because the IGLLB data were not grouped to represent natural climatic episodes of the region which have been described above, estimates of economic impacts comparable to the 1968-1973 study cited above are not available. However, it would appear that the data for the 1968-1973 period represent a reasonable approximation of the economic significance of the increased frequency of occurrence of high net basin supplies during the post-1950 period. For example, comparison of the average annual lake levels between climate episodes, as presented in Tables 3 and 4, reveals that the difference between the lowest and highest supply periods are 0.48 feet for Lake Superior and 0.89 feet for Lakes Michigan and Huron for Plan SO-901. For the Basis-of-Comparison (BOC) data simulation, the maximum differences between climate periods were 0.29 feet for Lake Superior and 0.95 feet for Lakes Michigan and Huron.

Table 3 Means of Lake Levels (feet) — Lake Superior

	1900-1919			1920-1949			1950-1975		
	(a) SO-901	(b) BOC	(a)-(b)	(a) SO-901	(b) BOC	(a)-(b)	(a) SO-901	(b) BOC	(a)-(b)
Jan	600.50	600.32	.18	600.01	599.98	.03	600.27	600.26	.01
Feb	0.30	0.10	.20	9.82	9.79	.03	0.08	0.07	.01
Mar	0.17	9.96	.21	9.71	9.68	.03	9.97	9.96	.01
Apr	0.22	9.99	.23	9.81	9.79	.02	0.08	0.07	.01
May	0.50	0.26	.24	0.10	0.08	.02	0.40	0.41	-.01
Jun	0.81	0.57	.24	0.38	0.38	.00	0.69	0.71	-.02
Jul	1.02	0.77	.25	0.58	0.59	-.01	0.87	0.89	-.02
Aug	1.14	0.90	.24	0.67	0.68	-.01	0.97	0.97	.00
Sept	1.20	0.97	.23	0.67	0.68	-.01	0.98	0.97	.01
Oct	1.15	0.94	.21	0.61	0.61	.00	0.88	0.87	.01
Nov	0.98	0.78	.20	0.46	0.45	.01	0.73	0.70	.03
Dec	0.73	0.53	.20	0.23	0.23	.00	0.52	0.48	.04
Year	600.73	600.51	.22	600.25	600.24	.01	600.54	600.53	.01

Source: University of Wisconsin-Madison 1975.

Table 4 Means of Lake Levels (feet) — Lakes Michigan-Huron

	1900-1919			1920-1949			1950-1975		
	(a) SO-901	(b) BOC	(a)-(b)	(a) SO-901	(b) BOC	(a)-(b)	(a) SO-901	(b) BOC	(a)-(b)
Jan	578.11	578.12	-.01	577.27	577.25	.02	577.70	577.75	-.05
Feb	8.08	8.09	-.01	7.24	7.22	.02	7.65	7.69	-.04
Mar	8.16	8.20	-.04	7.32	7.30	.02	7.70	7.74	-.04
Apr	8.40	8.44	-.04	7.56	7.54	.02	7.96	8.00	-.04
May	8.73	8.77	-.04	7.87	7.84	.03	8.31	8.34	-.03
Jun	8.98	9.03	-.05	8.12	8.08	.04	8.55	8.57	-.02
Jul	9.09	9.14	-.05	8.22	8.18	.04	8.67	8.69	-.02
Aug	9.05	9.09	-.04	8.14	8.10	.04	8.64	8.67	-.03
Sept	8.90	8.93	-.03	7.97	7.93	.04	8.49	8.53	-.04
Oct	8.70	8.72	-.02	7.74	7.71	.03	8.28	8.32	-.04
Nov	8.47	8.51	-.02	7.53	7.50	.03	8.08	8.13	-.05
Dec	8.30	8.31	-.01	7.35	7.31	.04	7.91	7.97	-.06
Year	578.58	578.61	-.03	577.69	577.66	.03	578.16	578.20	-.04

Source: University of Wisconsin-Madison 1975.

C. Lake Level Response to Long-Term Climatic Variations

In the first section of this report it was shown that the historical record contains evidence of three distinct episodes of climatic conditions for the Great Lakes region. The three episodes included a period beginning in the middle 1800s and extending up to about 1920, a second period lasting from about 1920 to about 1950, and a recent period extending from about 1950. Previous analyses by the working groups of the International Joint Commission, represented by the Great Lakes Levels Board, had not considered comparative analyses of the data based upon natural climatic episodes. The present effort involved comparative analyses of mean monthly lake levels and their standard deviations for the three climatic episodes described above. Data were obtained through use of U.S. Army Corps of Engineers computer programs which simulated both a standardized regimen of lake levels and lake levels for the various alternative management schemes representing the period from 1900 onward. Because the data were limited to a starting date of 1900, only the last twenty years of the first climatic episode were represented in the present analysis of hydrologic differences. Furthermore, time constraints limited the comparative analysis to Plan SO-901.

The data associated with the standardized regimen represent a Basis-of-Comparison (BOC) against which the effects of Plan SO-901 were compared. The BOC data primarily reflect hydrologic conditions and regulation rules which were in effect from the period of September 1955 to January 30, 1973.* A comparison of the differences in mean monthly lake levels is presented in Table 3 for Lake Superior and Table 4 for Lakes Michigan and Huron. Examination of the two tables reveals that differences in mean levels between the magnitudes for Plan SO-901 and the magnitudes for the BOC controlled regimen are relatively conservative despite the fact that significant differences in the general levels of lakes occur for the three climatic episodes. For example, Lake Superior's maximum monthly mean level under Plan SO-901 is 601.20 for the period 1900-1919, 600.67 for the period 1920-1949, and is 600.98 for the period 1950-1975. For Lake Michigan and Lake Huron the maximum monthly mean levels for Plan SO-901 are 579.09 for the period 1900-1919, 578.22 for the period 1920-1949, and 578.67 for the period 1950-1975. The relative differences between mean levels for the episodes are approximately the same for the BOC data as for the SO-901 data (Tables 3 and 4, Figures 2 through 5). The standard deviations for each of the monthly mean lake levels are presented in Tables 5 and 6. A t-test was conducted to determine if statistically significant differences existed between the mean lake levels for the month representing the maximum level on each of the two lake systems. The tests were conducted on BOC data for the month of September for Lake Superior and on BOC data for the month of July for Lakes Michigan and Huron. The results of the tests are shown in Table 7.

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* A detailed description of the assumptions for the BOC simulation can be found in IGLLB 1973, Main Report, pp. 64-67.

TABLE 5 STANDARD DEVIATIONS OF LAKE LEVELS (FEET) — LAKE SUPERIOR

	1900-1919			1920-1949			1950-1975		
	(a) SO-901	(b) BOC	(a)-(b)	(a) SO-901	(b) BOC	(a)-(b)	(a) SO-901	(b) BOC	(a)-(b)
Jan	.38	.44	-.06	.43	.48	-.05	.57	.41	.16
Feb	.38	.44	-.06	.43	.49	-.06	.62	.42	.20
Mar	.34	.41	-.07	.46	.53	-.07	.62	.41	.21
Apr	.35	.43	-.08	.49	.56	-.07	.62	.42	.20
May	.36	.43	-.07	.49	.58	-.09	.62	.41	.21
Jun	.33	.38	-.05	.50	.61	-.11	.62	.41	.21
Jul	.31	.35	-.04	.54	.61	-.07	.64	.41	.23
Aug	.30	.31	-.01	.52	.55	-.03	.64	.40	.24
Sep	.32	.38	-.06	.48	.52	-.04	.59	.42	.17
Oct	.36	.40	-.04	.47	.48	-.01	.57	.42	.15
Nov	.35	.38	-.03	.45	.49	-.04	.55	.42	.13
Dec	.32	.39	-.07	.44	.49	-.05	.55	.40	.15
Year	.51	.54	-.03	.59	.64	-.05	.70	.54	.16

Source: University of Wisconsin-Madison 1975.

TABLE 6 STANDARD DEVIATIONS OF LAKE LEVELS (FEET) — LAKES MICHIGAN-HURON

	1900-1919			1920-1949			1950-1975		
	(a) SO-901	(b) BOC	(a)-(b)	(a) SO-901	(b) BOC	(a)-(b)	(a) SO-901	(b) BOC	(a)-(b)
Jan	.53	.58	-.05	.86	.97	-.11	1.23	1.43	-.20
Feb	.52	.57	-.05	.84	.96	-.08	1.21	1.42	-.21
Mar	.53	.58	-.05	.86	.97	-.11	1.22	1.41	-.19
Apr	.56	.63	-.07	.90	1.01	-.11	1.23	1.41	-.18
May	.58	.64	-.06	.94	1.04	-.10	1.24	1.41	-.17
Jun	.60	.67	-.07	.97	1.07	-.10	1.25	1.45	-.20
Jul	.59	.66	-.07	.98	1.09	-.11	1.28	1.48	-.20
Aug	.57	.66	-.09	.99	1.10	-.11	1.28	1.48	-.20
Sep	.51	.59	-.08	.97	1.08	-.11	1.26	1.45	-.19
Oct	.48	.56	-.08	.94	1.06	-.12	1.23	1.42	-.19
Nov	.47	.55	-.08	.91	1.04	-.13	1.23	1.42	-.19
Dec	.51	.56	-.05	.89	1.00	-.11	1.22	1.41	-.19
Year	.65	.71	-.06	.98	1.08	-.10	1.27	1.46	-.19

Source: University of Wisconsin-Madison 1975.

TABLE 7 STATISTICAL TESTS OF SIGNIFICANCE OF CLIMATE IMPACTS ON MEAN LAKE LEVELS (FEET)

Lake Superior — Average BOC Levels During September

	$\overline{X}$	s
1900-1919	600.97	0.38
1920-1949	600.68	0.52
1950-1975	600.97	0.42

(1900-1919) vs. (1920-1949): t = 2.00; significant at 0.06 probability level
(1920-1949) vs. (1950-1975): t = 2.02; significant at 0.05 probability level

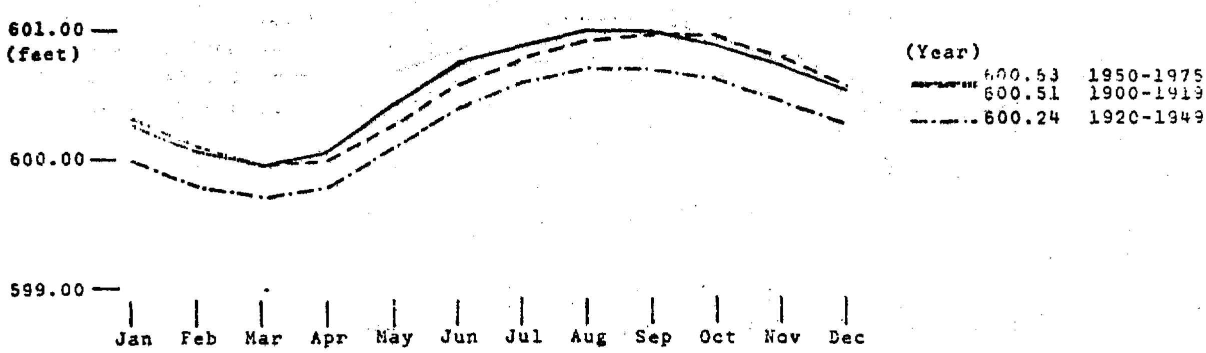
Lakes Michigan and Huron — Average BOC Levels During July

	$\overline{X}$	s
1900-1919	579.14	0.66
1920-1949	578.18	1.09
1950-1975	578.69	1.48

(1900-1919) vs. (1920-1949): t = 3.53; significant at 0.001 probability level
(1920-1949) vs. (1950-1975): t = 1.45; no statistically significant difference

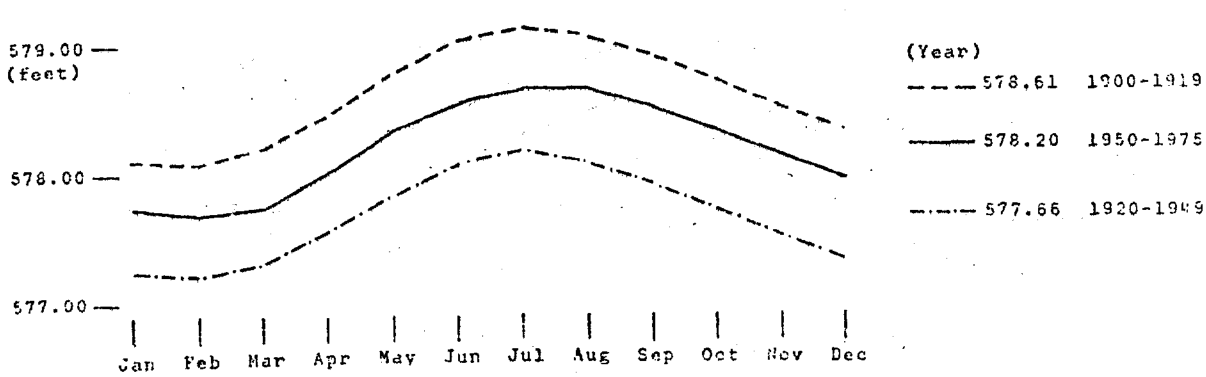
$\overline{X}$ = the mean; s = the standard deviation

FIGURE 2 SUPERIOR BOC LEVELS



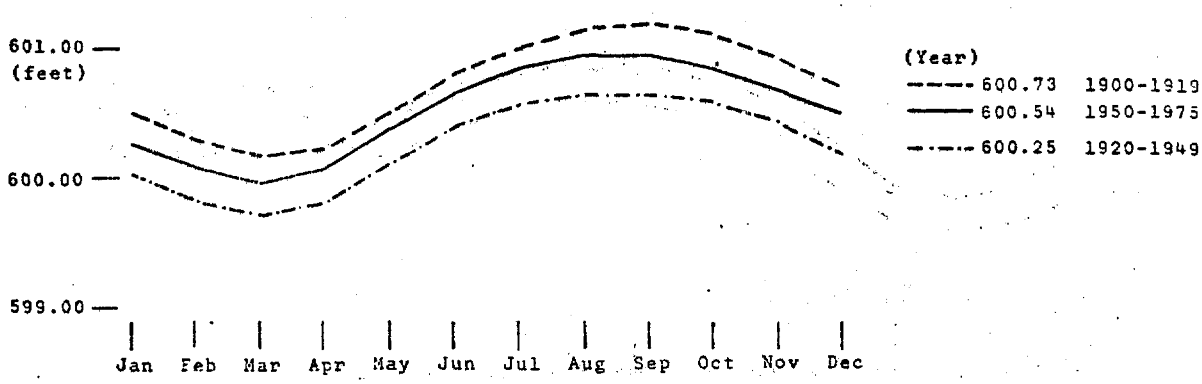
Source: University of Wisconsin-Madison 1975.

FIGURE 3 MICHIGAN-HURON BOC LEVELS



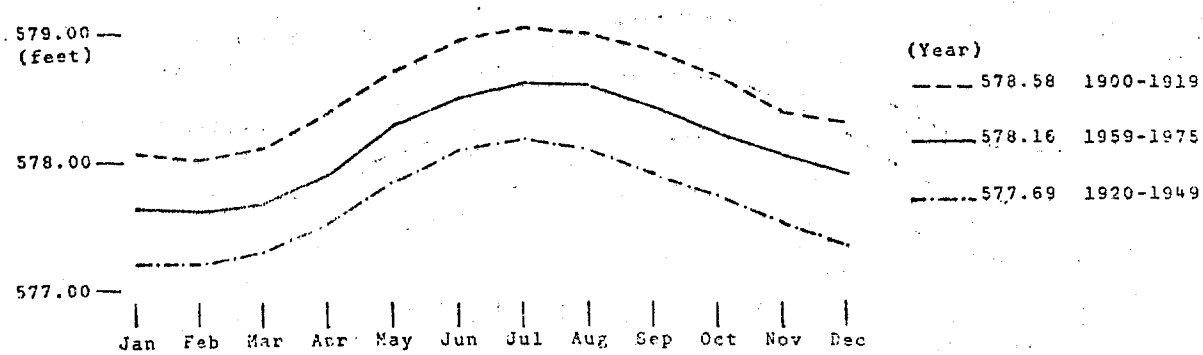
Source: University of Wisconsin-Madison 1975.

FIGURE 4 SUPERIOR SO-901 LEVELS



Source: University of Wisconsin-Madison 1975.

FIGURE 5 MICHIGAN-HURON SO-901 LEVELS



Source: University of Wisconsin-Madison 1975.

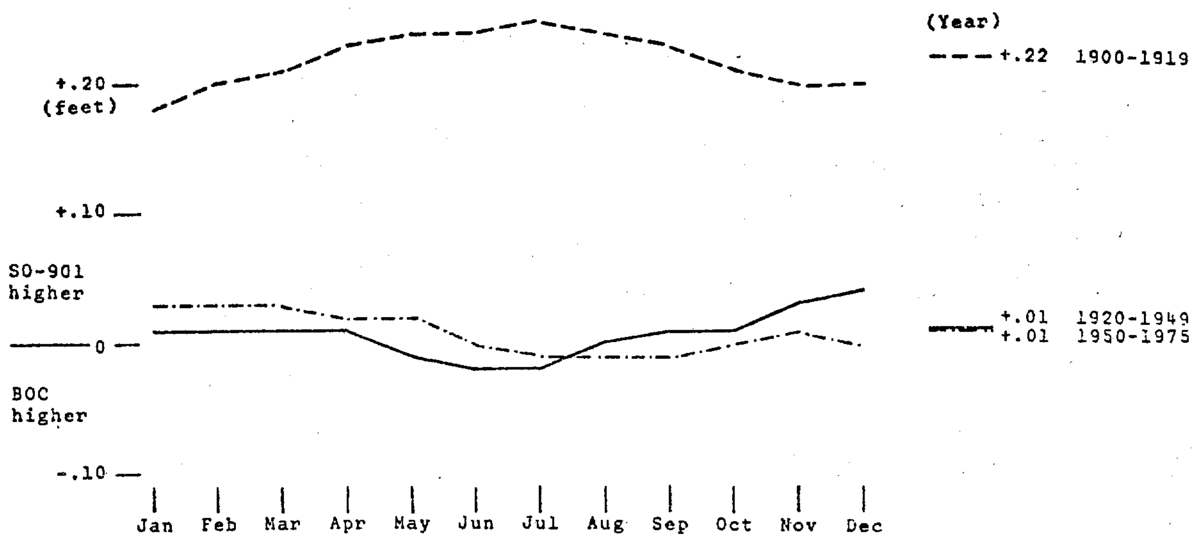
The t-test results indicated that statistically significant differences existed between lake levels for the period 1900-1919 versus 1920-1949 on both Lake Superior and Lakes Michigan and Huron, but that when the relatively dry period of 1920-1949 was compared against the wetter period of 1950-1975, a statistically significant difference was only apparent for the case of Lake Superior. The mean lake levels were also higher for the relatively wetter post-1950 period on Lakes Michigan and Huron, but the standard deviations of the lake levels on Lakes Michigan and Huron were sufficiently large in both climate periods to result in no statistically significant difference in the means of July lake levels (Tables 5 to 7). Because differences of the means and standard deviations for other months are roughly proportional to the relative differences represented by the high lake level months of September and June, the test results in Table 7 can be viewed as a general index of the significance of climate on lake levels for all months (Tables 3 to 6, Figures 2 to 5).

D. Relative Impact of Lake Level Management

Inspection of Tables 3 and 4 and Figures 2 to 5 shows that the annual range of average monthly lake levels are approximately the same for each of the three climate episodes for both Plan SO-901 and for the standardized BOC data. The similarities in the annual cycles of mean lake levels suggest that Plan SO-901 preserves the annual cyclical variations produced by monthly variations in net basin supplies. Differences in means of lake levels over a period of years appear to be primarily related to climate rather than to specific management schemes. Although the climate related differences in mean monthly lake levels for the three climate regimes illustrated in Figures 2 to 5 are relatively small, the reader may recall from the preceding section on economic impacts of climate variations that small differences in lake levels may result in large economic impacts.

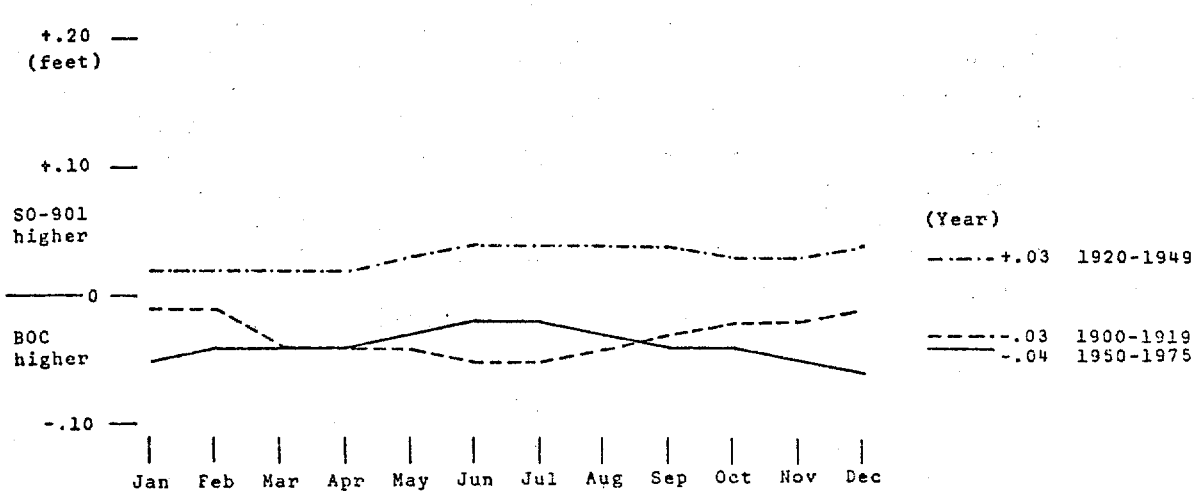
Although climate is responsible for the general differences in mean lake levels over periods of years, management plans such as SO-901 do have significant impacts on the variation in lake levels. For example, it may be observed in Figure 6 that Plan SO-901 generally results in Lake Superior being somewhat higher than it would normally be under the BOC mode of regulation. In contrast, Figure 7 indicates that Plan SO-901 tends to slightly reduce the monthly levels of Lakes Michigan and Huron during relatively wet episodes of climate and to increase their levels during a relatively dry episode such as represented by the period 1920-1949. The effect of Plan SO-901 on the standard deviation of monthly mean levels is especially apparent. During the past few years of above average net basin supplies to the Great Lakes, the impact of Plan SO-901 would have been to increase the variation of monthly levels on Lake Superior by approximately 0.20 feet and lower the variation of monthly levels on Lakes Michigan and Huron by a similar amount (Tables 5 and 6; Figures 8 and 9). The data for the three climate episodes suggest that variations in average monthly lake levels would have been greater under the BOC management scheme than for Plan SO-901 for all cases on Lakes Michigan and Huron. On Lake Superior, the BOC management scheme would have resulted in higher variations than would have resulted from Plan SO-901 during the two climate episodes of the pre-1950 period. However, since 1950, Plan SO-901 would have greatly increased the standard deviations of monthly lake levels on Lake Superior relative to what they would have been for the BOC scheme

FIGURE 6 LAKE SUPERIOR DIFFERENCES IN MEANS (SO-901 - BOC)



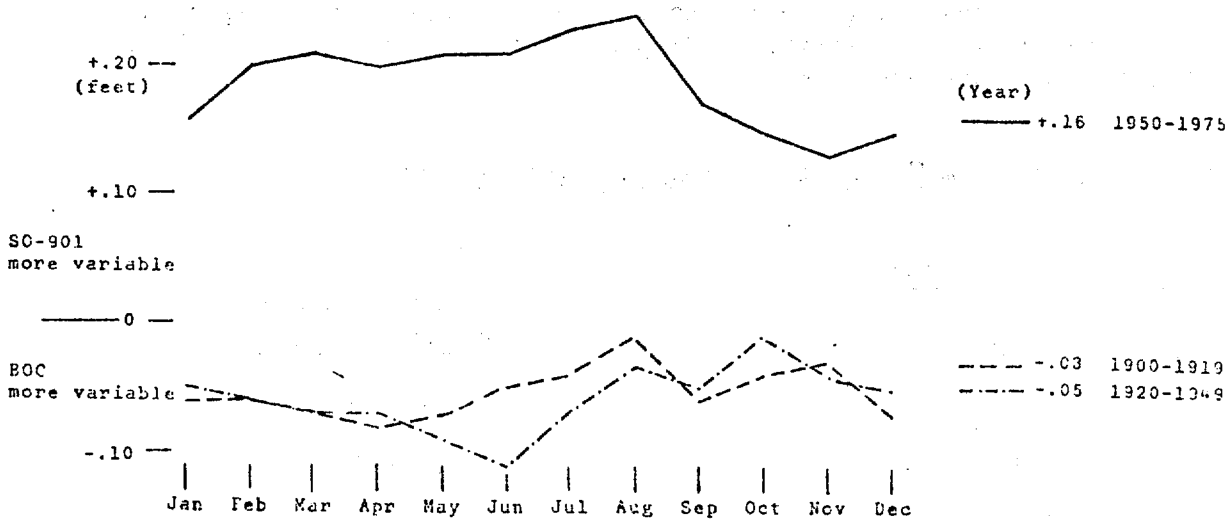
Source: University of Wisconsin-Madison 1975.

FIGURE 7 LAKES MICHIGAN-HURON DIFFERENCES IN MEANS (SO-901 - BOC)



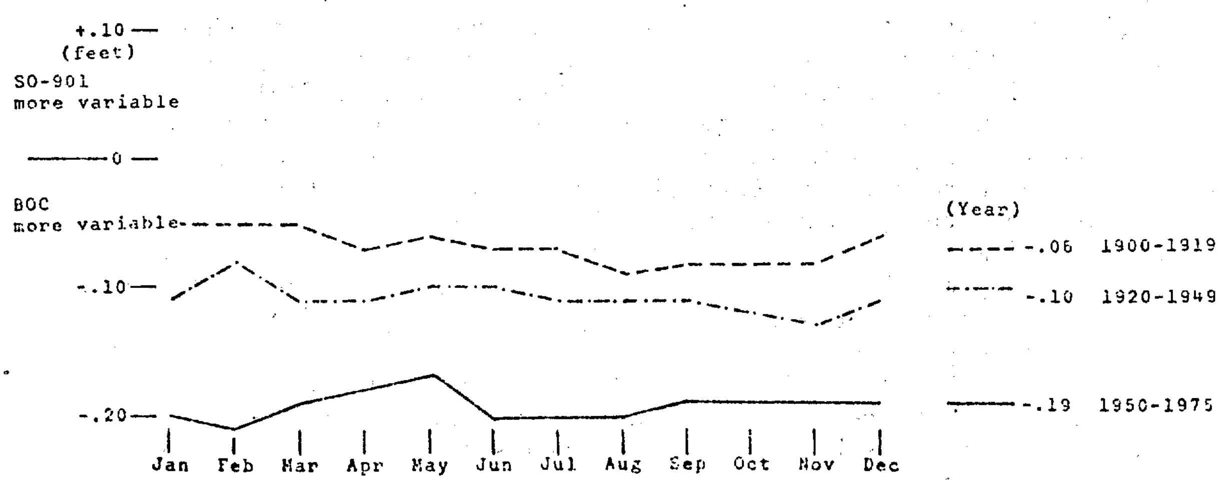
Source: University of Wisconsin-Madison 1975.

FIGURE 8 LAKE SUPERIOR DIFFERENCES IN STANDARD DEVIATIONS (SO-901 - BOC)



Source: University of Wisconsin-Madison 1975.

FIGURE 9 LAKES MICHIGAN-HURON DIFFERENCES IN STANDARD DEVIATIONS (SO-901 - BOC)



Source: University of Wisconsin-Madison 1975.

of management. It is unclear why the standard deviations of monthly lake levels for Plan SO-901 were not higher for the relatively high supply period of 1900-1919 as they were in the recent high supply period of the post-1950s. The explanation may relate to limitations on the amount of between lake balancing which can be achieved relative to disproportionate inputs of net basin supplies to the two lake systems (Table 8).

TABLE 8 NET BASIN SUPPLIES FOR THREE CLIMATIC EPISODES

Lake Superior Basin

Period	Cubic Feet Per Second Annual Average Input
1900-1919	870,000
1920-1949	829,000
1950-1973	921,000

Lakes Michigan and Huron Basin

Period	Cubic Feet Per Second Annual Average Input
1900-1919	1,411,800
1920-1949	1,255,600
1950-1973	1,332,000

Source: IGLLB 1973, Appendix B, pp. B-95—B-100.

The reader may recall from discussion of the generalized loss curves, developed by the IGLLB to estimate costs and benefits to shore interests that small differences in mean lake levels are associated with relatively large adjustments in economic gains and losses (IGLLB 1973, Main Report, p. 235). The IGLLB data suggest that especially large damages to Lake Superior shore property interests would result from implementation of Plan SO-901 and Plan SEO-42P during climate episodes characterized by above normal net basin supplies as occurred in the late 1960s and early 1970s. For the case of Plan SO-901 during above normal supply periods as described, the projected benefits to shore property on the combined system of Lakes Michigan and Huron would not be enough to offset damages to shore property on Lake Superior. While the IGLLB, Main Report, data (p. 235) indicate that over the entire base period of study, 1900-1967, Regulation Plan SO-901 would apparently produce positive benefits for the combined shore property interests on Lakes Superior, Michigan and Huron, this base period has been shown to be characterized by a somewhat abnormal climate in relation to climate characteristics of the last 150-200 years. There is a reasonable chance that the high supply conditions, which have characterized the past few years, may continue for another one or two decades. If a continuation of high supplies is experienced, then damages to shore property on Lake Superior may well exceed the benefits to the shore property interests on Lakes Michigan and Huron. Given the reasonable chance for continued high net basin supplies to the Great Lakes during the next one or two decades, it is quite possible that the state of Wisconsin, with shore interests on both lake systems, could experience a total net loss for the combined shore property interests on Lake Superior and Lake Michigan.

E. SUMMARY AND CONCLUSIONS

This section examined the influence of climate on characteristics of the hydrologic data base utilized by the Levels Board to formulate lake level management plans. Studies of historical variations of climate reveal that three principal episodes of climate may be recognized for the last 150 years in the Great Lakes region. The first episode, which culminated about 1920, and the most recent episode which began about 1950, include many years characterized by conditions which were cooler and wetter than the average over the long term. The middle episode, which spans the years from about 1920 to about 1950, is represented by a relatively high frequency of years having conditions which were warmer and drier than the average over the long term.

A large portion of the data base utilized by the IGLLB to evaluate alternative lake level management plans is characterized by relatively warm and relatively dry climatic conditions which may occur less frequently in the next few decades. Differences in means of lake levels, between periods in which levels have been averaged over a period of years, appear to be primarily related to climatic factors rather than to specific management schemes. The annual ranges of average monthly lake levels were found to be approximately the same for each of the three climatic episodes for conditions of both Plan SO-901 and the standardized BOC data. The similarity in annual cycles implies that Plan SO-901 preserves normal cyclical variations over the long term. However, the ability of Plan SO-901 to provide a balancing component to minimize the variance of lake levels has modest impacts on both the mean lake levels and their variances. The balancing process results in levels of Lake Michigan being slightly increased during periods of below normal net basin supplies. Plan SO-901 usually results in Lake Superior being somewhat higher than it normally would be under most conditions. Results of the study indicated that variations in average monthly lake levels on Lakes Michigan and Huron would usually be reduced under the conditions of Plan SO-901, but on Lake Superior, the general tendency of Plan SO-901 would be to usually increase the variations in average monthly lake levels.

In conclusion, two principal points emerge. First, climate is the principal cause of differences in mean monthly lake levels over a period of several years. Although some proposed artificial regulation schemes can produce relatively significant and immediate impacts on levels of specific lakes, such alternatives are prevented by current operating rules which reflect water needs of various interest groups and because of negative hydrologic impacts on downstream lake systems. The second point of concern relates to the relative importance of Lake Superior in the implementation of the "balancing concept" of Plan SO-901. Plan SO-901 generally increases the levels of Lake Superior over the long term. Generalized estimates by the IGLLB of shore property damages on the Great Lakes reveal that Lake Superior usually experiences losses under Plan SO-901 while net benefits occur on other Great Lakes shores. During periods of high net basin supplies, as occurred from 1968-1973, the increased damages on Lake Superior shores under Plan SO-901 were not offset by benefits to shore interests on Lakes Michigan and Huron, although benefits can be shown when all Great Lakes are considered simultaneously. Since there is a reasonable probability that "above average" net basin supplies may occur more frequently in the next two decades than as indicated by their average period of recurrence as recorded in the IGLLB data base, it implies that shore property interests in Wisconsin, Minnesota, and Michigan could suffer major losses under Plan SO-901 during a relatively large number of years in the immediate future. Because Lake Superior shore property interests must absorb an unusually large part of the damages related to Plan SO-901, a compensation program should be considered.

IV. EFFECTS OF THE PROPOSED REGULATION PLANS

INTRODUCTION

A relatively large number of plans have been developed by the International Great Lakes Levels Board (IGLLB) as possible alternatives for regulation of Great Lakes water levels (Appendix B, pp. B-37—B-124). A principal characteristic of the plans involves a design to minimize, for the Great Lakes system, the departure of water levels from their long-term average levels. Economic analyses by the IGLLB for the various plans revealed that regulatory schemes requiring extensive structural modifications would not produce favorable cost/benefit ratios. Some of the proposed plans which were found by the IGLLB to be associated with relatively favorable cost/benefit ratios and which have subsequently been given significant attention as possible alternatives for lake level regulation include: Plan SO-901, Mods 7 and 8 of Plan SO-901, SEO-42P, and SEO-17P. These five plans do not require major structural modifications in the waterways connecting the individual lakes. However, all five of the plans depend heavily on the use of Lake Superior as a reservoir to increase the flow of water to the downstream lakes during periods of below normal net basin supplies to the Great Lakes system or to decrease the flow of water to the downstream lakes during periods of above normal net basin supplies to the Great Lakes system.

In regard to the use of Lake Superior as a reservoir, the five regulation plans described above for the "SO" and "SEO" series all incorporate nearly the same operating rule for determination of the release of water from Lake Superior. This operating rule represents an attempt to minimize the departures of lake levels on Lakes Superior, Michigan, and Huron from their long-term 1900-1967 average magnitudes. The basic operation of this important procedure is described in the following section.

A. The Balancing Concept of SO Plans

The balancing concept of the "SO" plans, as noted above, involves the release of water from Lake Superior at a rate dependent upon how beginning-of-month levels on both Lake Superior and Lakes Michigan and Huron compare to their long-term respective mean levels for those respective dates. Hence, the objective of the SO-901 regulation rule is to minimize, for any month, the relative monthly departures of lake levels of Lakes Superior and Michigan-Huron from their long-term mean monthly levels. This is expressed by the following equation

$$\frac{S-\overline{S}}{\sigma S} = \frac{H-\overline{H}}{\sigma H} \qquad (1)$$

where: S = beginning-of-the-month Lake Superior elevation for the given month

H = beginning-of-the-month Lakes Michigan-Huron elevation for the given month

$\overline{S}$ = average beginning-of-the-month Lake Superior elevation for the given month

$\overline{H}$ = average beginning-of-the-month Lakes Michigan-Huron elevation for the given month

σS = standard deviation of the beginning-of-the-month Lake Superior elevation

σH = standard deviation of the beginning-of-the-month Lakes Michigan-Huron elevation

$\overline{S}$, $\overline{H}$, σS, σH, are derived from the Basis-of-Comparison data.

The outflow from Lake Superior is determined by equation (2) in relation to the long-term monthly average outflow, as expressed in the following equation:

$$Q_1 = \overline{Q} + A\ [S - (\overline{S} + (H-\overline{H})\ \frac{\sigma S}{\sigma H})] \qquad (2)$$

where: Q_1 = initial outflow calculation in cfs

$\overline{Q}$ = long-term average outflow in cfs (1900-1967)

A = rate of adjustment (200,000 cfs/ft)

Since the constant A, called the "rate of adjustment," is the only element subject to manipulation, it is very significant in determining the discharge to be allowed in each month (IGLLB 1973, Appendix B, Vol. 1, p. 40). In determining the best value of A, the Levels Board used different values of A in the Equation for Q, and the value that had the best estimated economic results on Lakes Superior, Michigan-Huron, and Erie for the 1900-1967 study period was chosen to be 200,000 cfs/ft. Thus, the operation of the release rule is based on the adequacy of the economic analysis.

For each month there are minimum and maximum outflow constraints at the compensating works in the St. Marys River. The actual amount of water released is as follows:

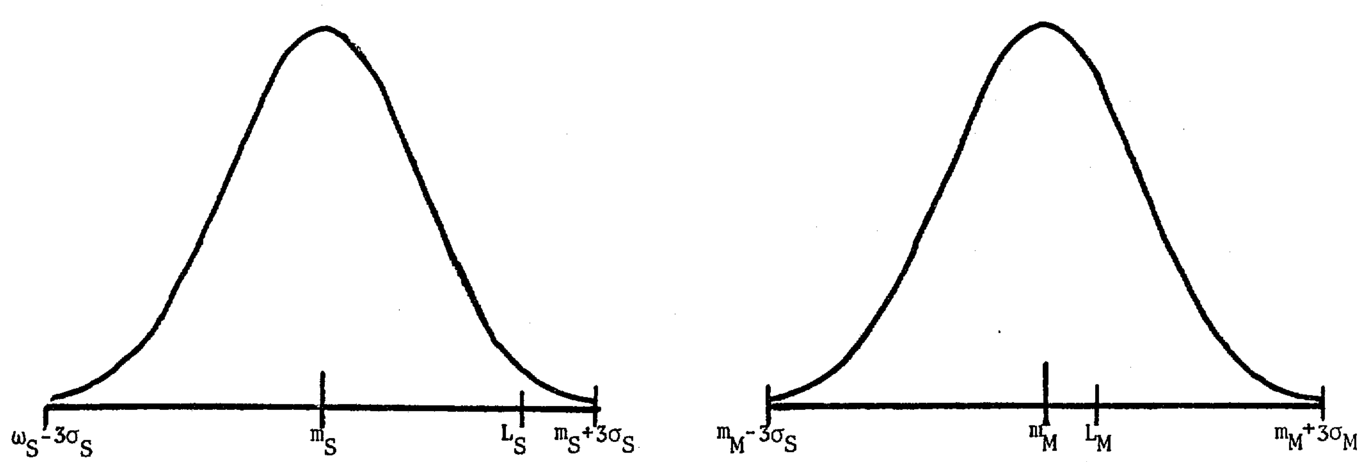
If Q min. $\leq Q_1 \leq$ Q max., then Q_1 is released.

If $Q_1 \leq$ Q min., then Q min. is released.

If $Q_1 \geq$ Q max., then Q max. is released.

The actual operation of an "SO" plan, such as SO-901, is best described through consideration of a hypothetical situation. For example, in Figure 10, let L denote the beginning-of-month level for a lake, m denote the mean long-term 1900-1967 monthly level for a particular beginning-of-month observation, and let σ denote the standard deviation of the mean monthly levels for the 1900-1967 period. The Lake Superior discharge for a plan such as SO-901 would then be determined by comparing current observed beginning-of-month levels for Lakes Superior and Michigan and Huron relative to the probability distributions of monthly lake levels for the two lake systems as shown in Figure 10. For example, in Figure 10 the level of Lake Superior, L_S, is much higher with respect to its average than is the level of Lake Michigan, L_M. So in this instance the rule calculation would call for a large increase of the outflow from Lake Superior in order to move the L_S level closer to its average value at the expense of causing the level of Lake Michigan, L_M, to depart somewhat further from its average, thus balancing the levels.

FIGURE 10 PROBABILITY DISTRIBUTION OF HYPOTHETICAL MONTHLY LEVELS OF LAKE SUPERIOR AND LAKES MICHIGAN-HURON



According to rule procedures, the tentative outflow, thus calculated, is then checked against last month's outflow to determine if it represents a change of more than plus or minus 30,000 cfs. If it does, then the tentative outflow becomes last month's outflow plus or minus 30,000 cfs. If the result of these calculations is less than 65,000 cfs, then the gates are set to pass a minimum outflow of 55,000 cfs. If the result of the calculation is greater than 85,000 cfs for a winter month (December through April) then the tentative outflow is set at 85,000 cfs.

Once the tentative outflow is calculated, rating curves are used to determine the number of gates required to be open in order to approximate the desired Lake Superior outflow (IGLLB, 1973, Main Report, p. 270). After the discharge from Lake Superior has been determined, an estimate of the expected monthly mean level of Lake Superior is made by subtracting the tentative outflow based upon estimates of supplies for the coming month and adding this to the beginning-of-month level to obtain an estimate of the end-of-month level. The beginning- and end-of-month levels are then averaged to obtain the mean monthly level.

From the tentative outflow, the number of gates to be opened is estimated by a mathematical representation (rating curves) of the outflow as dependent on the mean lake level. For example, let Q_G denote the calculated outflow with G gates open, and Q denote the tentative outflow. One finds the number of gates G such that:

$$Q_{(G-1)} < Q < Q_{(G)}$$

where: $Q_{(G-1)}$ is the outflow with one less gate open. If Q is closer to $Q_{(G-1)}$ in the summer and always during the winter, G-1 gates open are used. In the summer if Q is closer to $Q_{(G)}$, then G gates open are used. Either $Q_{(G-1)}$ or $Q_{(G)}$ is used to obtain a new estimate of the monthly mean level and then a new outflow is calculated. If there has been no change, this is the outflow. Otherwise the process is repeated until the monthly mean and the outflow stabilize at a single value for each.

The above constitutes a simplified description of the basic aspects of the release of Lake Superior water according to "SO" regulation plans. In practice the Corps of Engineers undertakes much more elaborate calculations to obtain estimates of discharges to be recommended to the Lake Superior Board of Control for control of Lake Superior outflow. The more elaborate procedure involves weather forecasts, projections of supplies over the next 12 months, routings over the next 12 months to determine estimated lake levels, and estimates of what might happen under extreme supply conditions. The elaborate procedure is used in an attempt to guarantee that Lake Superior will never rise over the 602 feet level set by international agreement.

Plans SO-901 Mods 7 and 8 follow exactly the same procedure for determining the Lake Superior outflow as the general Plan SO-901, except that different means and standard deviations are used in the "rule" calculations. In both of the Mod plans the mean beginning-of-month levels of Lakes Michigan and Huron remain unchanged from those used in SO-901. However, in Mod 7 all Lake Superior beginning-of-month levels are reduced by 1/2 foot, and in Mod 8 all Lake Superior beginning-of-month levels are reduced by 3/4 foot.

Plans SEO-42P and SEO-17P utilize the same Lake Superior release rule as for Plan SO-901. The only principal difference of the "SEO" plans for Plan SO-901 is that the "SEO" plans permit a larger discharge of water from Lake Erie during periods of abnormally high supplies. The larger discharges from Lake Erie during periods of excessive supplies are accomplished by increasing the outlet capacity of the Niagara River.

B. Hydrologic Impacts of Proposed Plans

In the following section, hydrologic impacts are evaluated for five alternative lake level regulation plans, including: Plan SO-901, Mods 7 and 8 of Plan SO-901, and Plans SEO-42P and SEO-17P. Discussion is limited to these five plans, although many other plans have been developed by the International Great Lakes Levels Board. The above plans were given special study because they have emerged as being the most relevant for possible implementation. The University study groups concentrated upon Plan SO-901, a plan which the IGLLB has presented as the regulation scheme that provides the most benefits for the least investments.

1. Impacts of Plan SO-901 on Lake Level Departures from Average

Because of the special status of Plan SO-901, an initial effort by the University team involved assessing the impact of this plan on the recurrence probabilities of average monthly lake levels. Specific magnitudes of mean monthly lake levels expected for Plan SO-901 were compared to corresponding mean monthly lake levels expected for the standardized Basis-of-Comparison (BOC) regulated levels by plotting probability graphs of the expected levels for each of the 12 months (Figures 11-22). The probability data for frequencies of lake levels of specific magnitudes were developed from information on mean monthly lake level frequencies simulated by computer programs representing the rules of operation for Plan SO-901 and the BOC.

Inspection of Figures 11-22 reveals that differences between the levels under Plan SO-901 and the BOC tend to be relatively modest for most months. The most obvious negative impacts of Plan SO-901 appear to be on Lake Superior where it is apparent that regulation has a general tendency to increase the variation about the mean and, for some months, to increase the magnitude of the modal (most frequently recurring) lake levels. Although Plan SO-901 was observed to reduce Lake Superior lake level probabilities by as much as 20% in the interval associated with the BOC mode, this change is accompanied by increased probabilities of 5-10% for intervals associated with the tails of the probability distributions of levels. The hydrologic impact of SO-901 is difficult to assess because of the relatively small range of levels associated with the probability distributions. For example, in Figure 21 it is difficult to interpret the significance of an approximately 25% reduction in the occurrence of Lake Superior lake level magnitudes in the modal interval in comparison to the modest increases of 3-5% for three intervals of lake levels in the upper range of the right hand tail of the probability distribution. It is noteworthy, however, that Plan SO-901, relative to the BOC regulation, increases the likelihood of higher lake levels on Lake Superior during the months having a high potential for storm occurrences, e.g., March, April, September, October, and November (Figures 13, 14, 19-22).

FIGURE 11 LAKE LEVEL FREQUENCY - JANUARY (1900-1973)

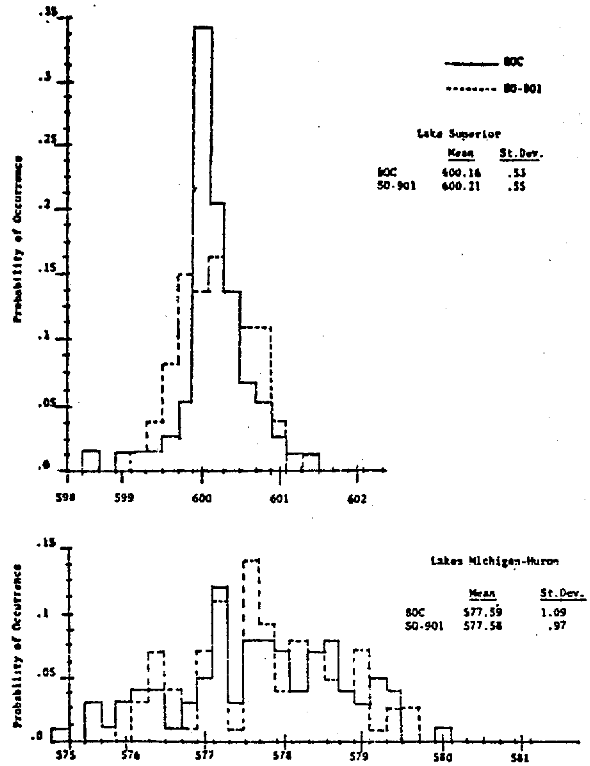
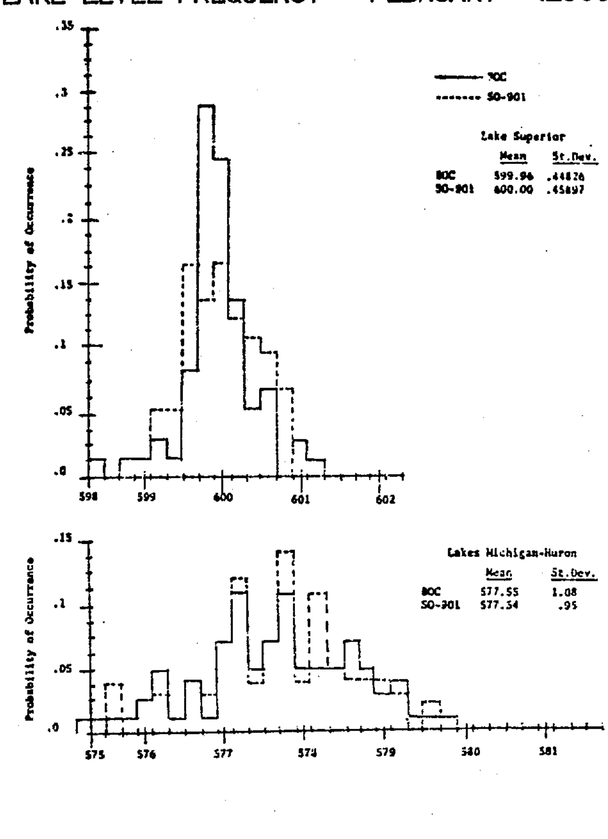


FIGURE 12 LAKE LEVEL FREQUENCY - FEBRUARY (1900-1973)



Source: University of Wisconsin-Madison 1975.

FIGURE 13 LAKE LEVEL FREQUENCY - MARCH (1900-1973)

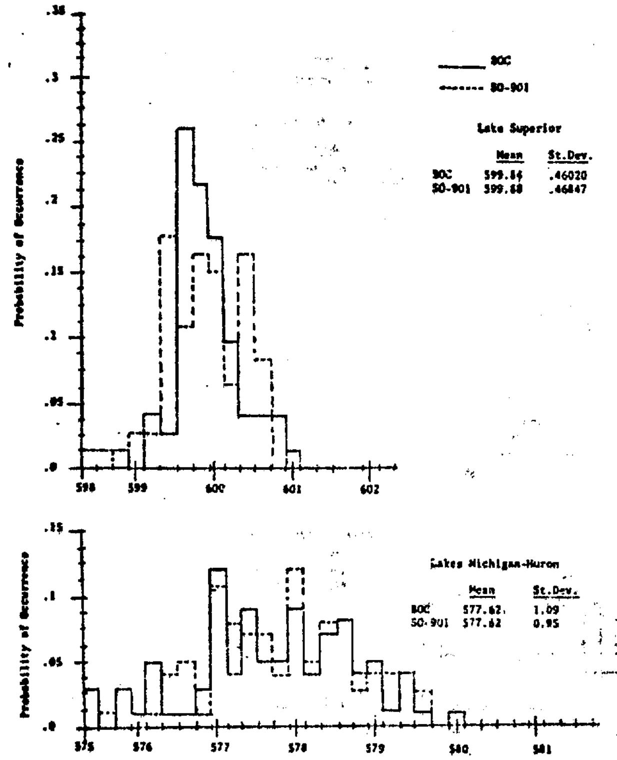
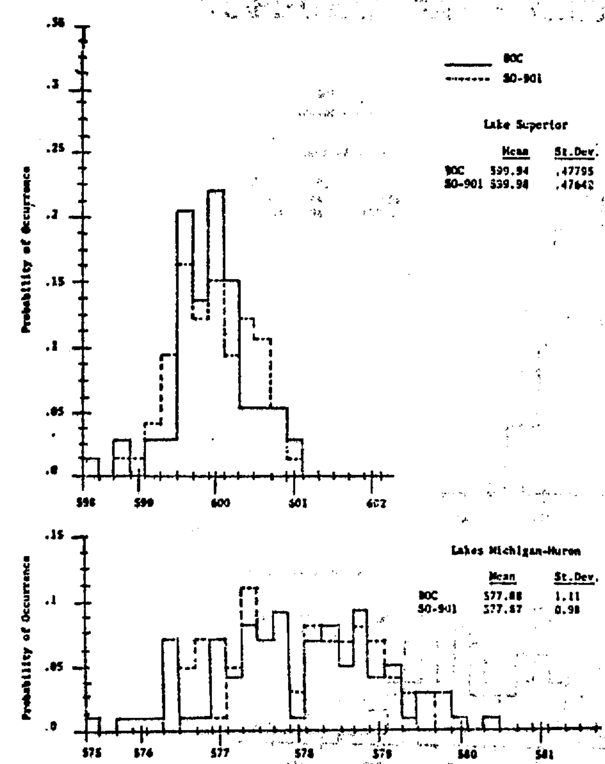


FIGURE 14 LAKE LEVEL FREQUENCY - APRIL (1900-1973)



Source: University of Wisconsin-Madison 1975.

FIGURE 15 LAKE LEVEL FREQUENCY - MAY (1900-1973)

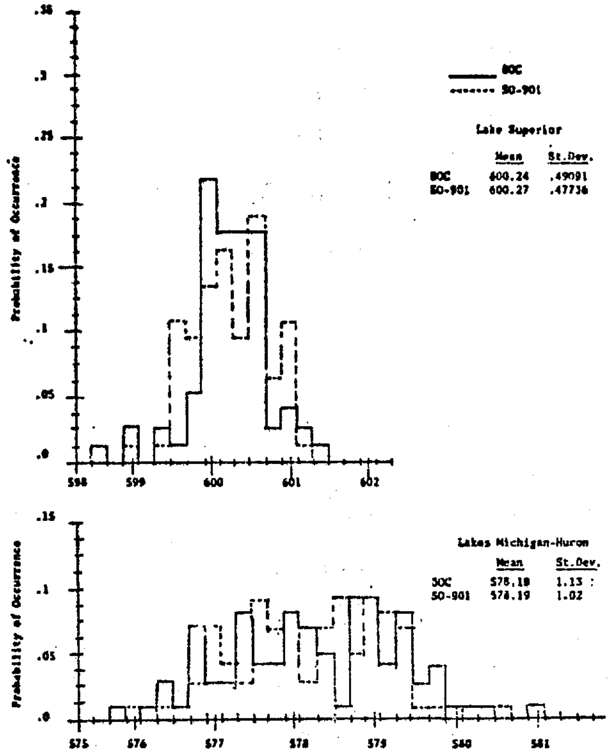
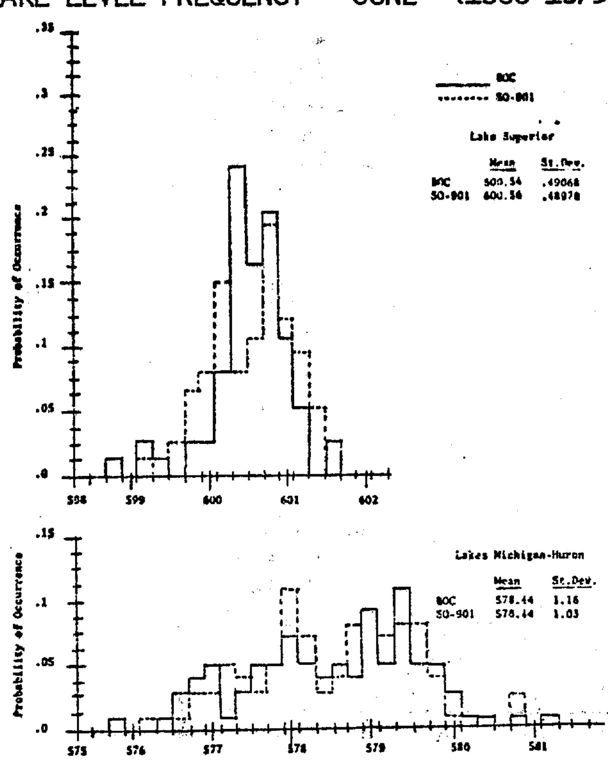


FIGURE 16 LAKE LEVEL FREQUENCY - JUNE (1900-1973)



Source: University of Wisconsin-Madison 1975.

FIGURE 17 LAKE LEVEL FREQUENCY - JULY (1900-1973)

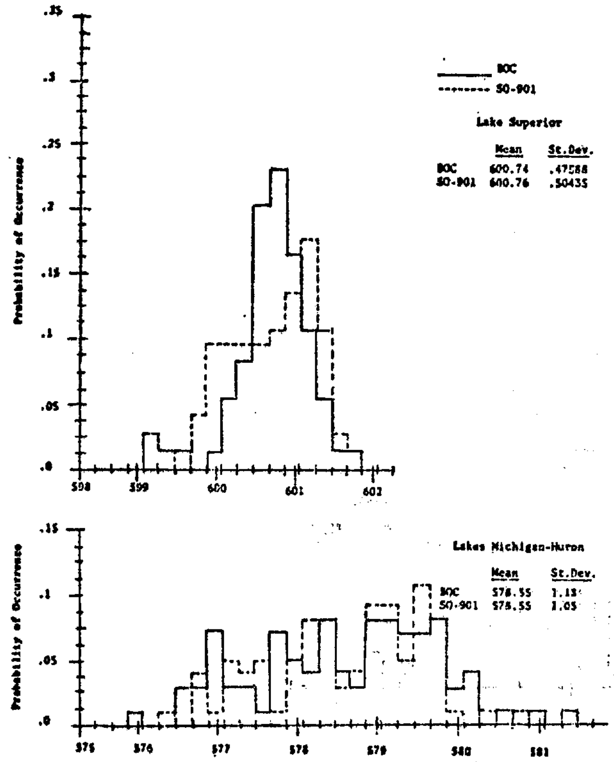
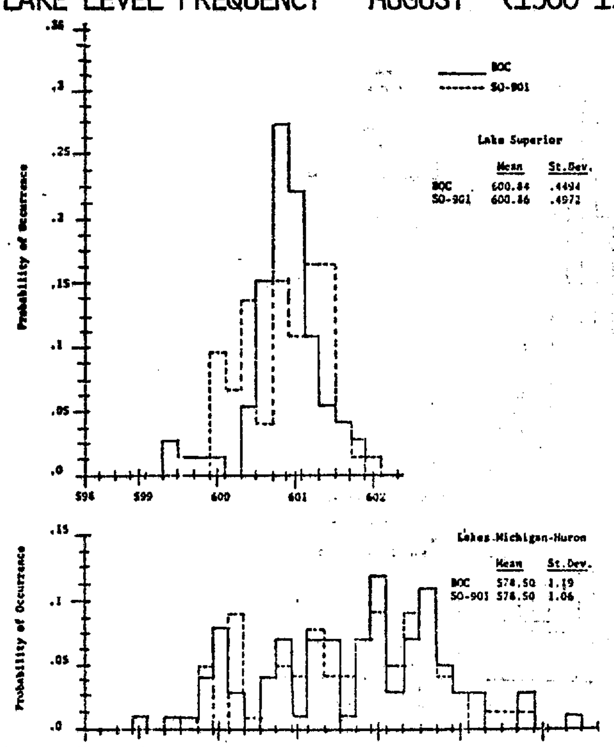


FIGURE 18 LAKE LEVEL FREQUENCY - AUGUST (1900-1973)



Source: University of Wisconsin-Madison 1975.

FIGURE 19 LAKE LEVEL FREQUENCY - SEPTEMBER (1900-1973)

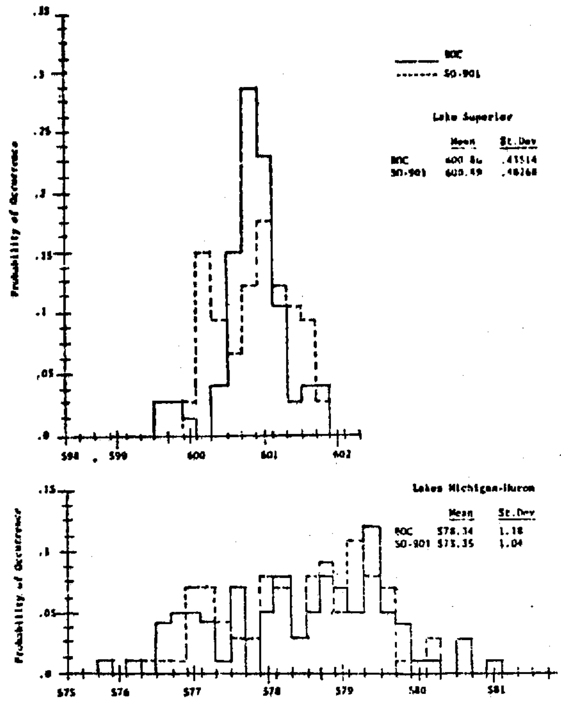
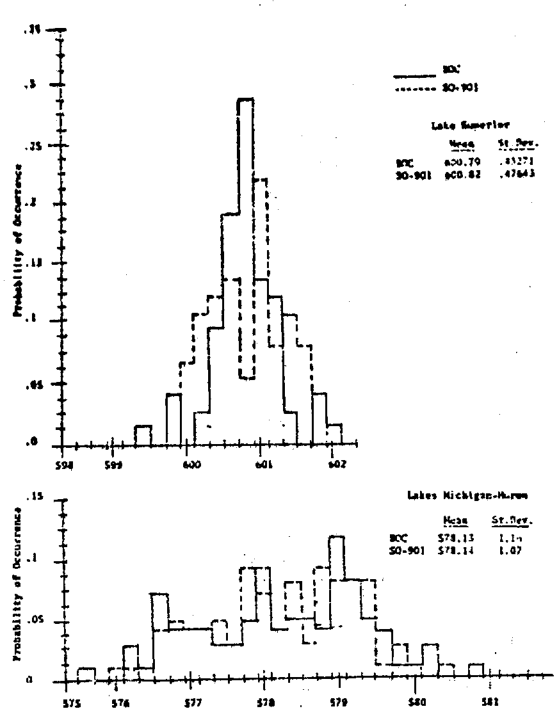


FIGURE 20 LAKE LEVEL FREQUENCY - OCTOBER (1900-1973)



Source: University of Wisconsin-Madison 1975.

FIGURE 21 LAKE LEVEL FREQUENCY - NOVEMBER (1900-1973)

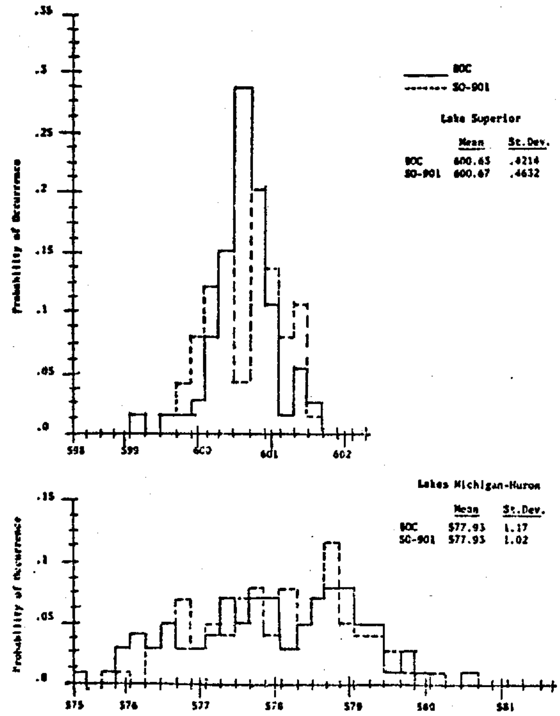
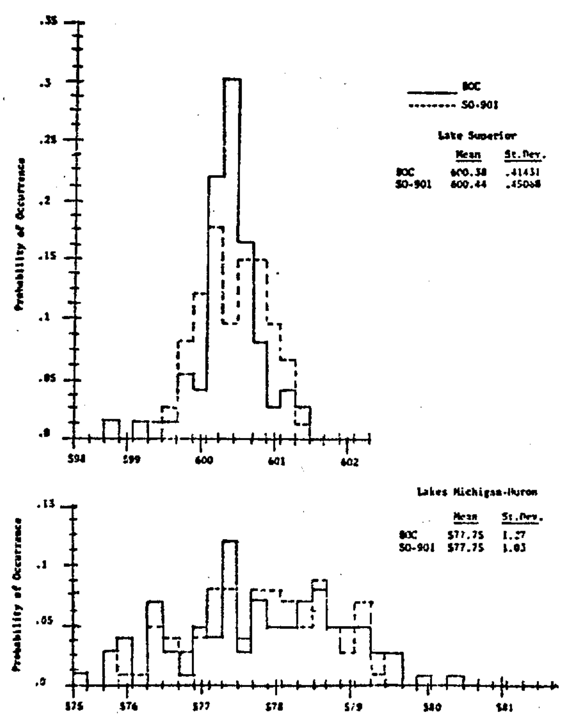


FIGURE 22 LAKE LEVEL FREQUENCY - DECEMBER (1900-1973)



Source: University of Wisconsin-Madison 1975.

The probability plots representing SO-901 and BOC expected lake levels on Lakes Michigan and Huron indicate that the effects of Plan SO-901 on recurrences of specific lake level magnitudes are much more evenly scattered over the probability distributions than for the case of Lake Superior. Probabilities of occurrence in most intervals are not altered by Plan SO-901 by more than 5% relative to the levels expected for the Basis-of-Comparison. The net effect of Plan SO-901 involves a modest decrease in the variation in magnitudes of average monthly lake levels. Little effect is apparent regarding differences in means of the probability distributions. On the basis of the long-term averages of monthly levels, Plan SO-901 has a favorable impact on Lakes Michigan and Huron by minimizing the occurrences of lake levels representing extreme deviations from the long-term mean.

In summary, regulation of lake levels under Plan SO-901, relative to the Basis-of-Comparison scheme of regulation, is relatively modest when judged over the long time span of 1900-1973. The long-term effects of regulation appear to be slightly negative to Lake Superior shore property interests and slightly beneficial to the same interests on Lakes Michigan and Huron. These effects can be exaggerated by climate variations as shown in section III of this hydrology report. Although the IGLLB sought to preserve the natural cycle of lake level variations normally observed during a year, the University investigators were surprised by the relatively small impact that lake level management actually imposed on the lake levels of the Great Lakes. The modest effects of management plans do not result from the regulation plans inability to significantly impact lake levels. Regulation could alter the magnitudes of lake levels, but this does not occur because complete regulation cannot be practiced at all times without causing negative hydrologic impacts elsewhere in the Great Lakes system. The limitation on how often the regulation plans work was described earlier in section III of this hydrology report where it was shown that limitations on the regulation plans result in climate being the principal cause of lake level related problems. The amount of time that lake level regulation can be practiced unconstrained varies with individual regulation plans and with the variations in net basin supplies throughout the course of a year. The variations in time of operation of the Plan SO-901 and Mods 7 and 8 of Plan SO-901 are discussed in the following section. Since the principal concern of the present investigation is with Lakes Superior, Michigan and Huron, and because the two SEO regulation plans use the same release rule for discharging water from Lake Superior as in Plan SO-901, the two SEO plans were not included in the analysis.

2. Limiting Constraints on Operation of Regulation Plans

The operating rules for Plan SO-901 and its derivatives are primarily limited by characteristics of the channel capacity and regulatory structures of the St. Marys River. The principal limitations are:

(a) maximum outflow for May-November to be 65,000 cfs plus 16 gates open

(b) maximum outflow for December-April to not exceed 85,000 cfs

(c) minimum outflow for any month to not drop below 55,000 cfs

(d) change in outflow from month-to-month to be limited to 30,000 cfs.

The limiting maximum discharge for the May-November period is approximately 120,000 cfs. During the months of April through July the input of net basin supplies to Lake Superior frequently exceeds 120,000 cfs and excess water accumulates on Lake Superior. Under conditions of average supplies throughout a year, the excess of the spring and summer could be removed during low supply periods of late fall and winter. However, the smaller outflow capacities of the cold season often result in a carry-over of excessive supplies from one year to the next. If excessive supplies are persistent, major damages can be expected from high lake levels. The following section describes the analysis used to estimate the percentage of time that Plan SO-901 and Mods 7 and 8 of Plan SO-901 would hve been fully operative for net basin supplies of the period 1900-1973. It is followed by the descriptive statistics representing the percentages of time that each of the above regulation plans would have been able to operate at full capacity under the conditions of net basin supplies of 1900-1973.

3. Analysis and Interpretation of Results

In order to determine the range of levels on the two lakes within which the outflow equation holds (i.e., $Q\ \text{min.} \leq Q_1 \leq Q\ \text{max.}$) it is necessary to generate four plotting points for each month on a graph whose axes represent Lake Superior levels and Lakes Michigan-Huron levels. These points describe a parallelogram within which Q_1 calculated by equation (2) is actually released.

The four points are generated by substituting for Q_1, the minimum and maximum outflow constraints for each month and for H, the minimum and maximum monthly mean levels over the historical record, and solving for S each time. Thus, the following four equations are used for each month.

$$\begin{aligned} S_1 &= \frac{Q\ \text{min.} - \overline{Q}}{A} + \overline{S} + (H\ \text{min.} - \overline{H})\ \frac{\sigma S}{\sigma H} \\ S_2 &= \frac{Q\ \text{max.} - \overline{Q}}{A} + \overline{S} + (H\ \text{min.} - \overline{H})\ \frac{\sigma S}{\sigma H} \\ S_3 &= \frac{Q\ \text{min.} - \overline{Q}}{A} + \overline{S} + (H\ \text{max.} - \overline{H})\ \frac{\sigma S}{\sigma H} \\ S_4 &= \frac{Q\ \text{max.} - \overline{Q}}{A} + \overline{S} + (H\ \text{max.} - \overline{H})\ \frac{\sigma S}{\sigma H} \end{aligned} \qquad (3)$$

Next the four equations are transformed into a linear programming formulation and solved as either a maximization or minimization problem. The objective function to be maximized or minimized is formed by separating out the constant terms, combining them, and expressing them as an equality constraint. The formulation is as follows:

$$\text{MIN/MAX}\quad S = \frac{Q_1}{A} + H\ \frac{\sigma S}{\sigma H} + Z \qquad (4)$$

subject to:

$$\begin{aligned} Q_1 &\leq Q\ \text{max.} \\ Q_1 &\geq Q\ \text{min.} \\ H &\leq H\ \text{max.} \\ H &\geq H\ \text{min.} \\ Z &= \overline{S} - \overline{H}\ \frac{\sigma S}{\sigma H} - \frac{\overline{Q}}{A} \end{aligned}$$

In maximizing or minimizing the above objective function, the linear programming model only utilizes Q max. and H max. or Q min. and H min. in combination, thus giving two of the four necessary plotting points. The other two points are derived by either adding or subtracting $\frac{Q\ max. - Q\ min.}{A}$, which represents the range, to the S min. and S max. values calculated from the linear program. Tables 9, 10, and 11 list by month, for the three SO-901 plans, the parameters: $\overline{Q}$, $\overline{S}$, $\overline{H}$, σS, σH, H min., H max., which are used in calculating the plotting points. The Q min. and Q max. values are found in Table 12. All of the parameters in Tables 9, 10, and 11 are measured over the 74-year record from 1900-1973 and are taken from the SO-901 computer programs using 1962 outlet conditions for Lake Huron. Tables 13, 14, and 15 list the two plotting points generated for each month and the range used to calculate the second two points for each month.

The next step was to develop a joint frequency distribution for levels on Lake Superior and Lakes Michigan and Huron for each month. This distribution is then superimposed on a parallelogram within which Q_1 calculated by equation (2) is actually released. This is accomplished by designating 0.2 feet intervals over the range of levels on each lake and tabulating the number of occurrences in each cell. Each cell represents an area on the graph. In order to estimate the maximum number of years that the operating rule is not bounded by outflow constraints, all cells lying predominantly or completely within the parallelogram are counted. The resulting count is then expressed as a percentage of the historical record. This value represents the maximum possible number of occurrence of Q min. $\leq Q_1 \leq$ Q max., the actual number being somewhat less.

Twelve graphs for each plan were produced using this method (Figures 23-58). On the graph for each month the percentage of the historical record for which the SO-901 regulation rule would have been operative is indicated. Table 16 summarizes this data.

To study how often the SO-901 regulation rule is operative during high supply periods to the lakes, the 75th percentile levels were labeled on each graph. These 75th percentile levels are derived by adding 0.67 standard deviations to the mean levels, assuming a normal distribution of lake levels. The number of occurrences of lake levels greater than the 75th percentile level for each lake, and for which Q min. $\leq Q_1 \leq$ Q max., were then tabulated and expressed as percentages of the historical record. This was also done for those occurrences for which levels on both lakes are each greater than the 75th percentile level. Tables 17 and 18 list the 75th percentile average monthly levels for each lake, for each plan. Tables 19, 20 and 21 list for Lake Superior and Lakes Michigan and Huron, by month, for the 74-year record, the percentage of occurrences of lake levels greater than the 75th percentile level for which operation of each of the respective plans would have been impeded by rule constraints. The annual average percentages representing unconstrained operation of Plans SO-901, Mod 7 and Mod 8 are 41%, 43% and 46%, respectively. The three percentages represent the upper limits, with the actual numbers being somewhat less. At all other times the release from Lake Superior is determined by minimum or maximum outflow constraints. Apparently the release rule is slightly more efficient during the late summer and early fall months, apparently attributable to the wider permissible range of outflows during these months. During the winter months the release rule is less flexible in that the difference between Q max. and Q min. is only 30,000 cfs, thus restricting the monthly outflow to a narrower range.

TABLE 9 MONTHLY OPERATING PARAMETERS FOR THE SO-901 REGULATION PLAN

Month	$\overline{Q}$	$\overline{S}$	$\overline{H}$	σS	σH	H Min.	H Max.
Jan	70	600.21	577.58	.53	.97	575.54	579.52
Feb	70	600.01	577.54	.56	.95	575.53	579.45
Mar	69	599.90	577.62	.54	.95	575.48	579.59
Apr	69	599.99	577.87	.56	.98	575.63	579.98
May	75	600.28	578.20	.57	1.02	575.91	580.40
Jun	79	600.57	578.44	.59	1.03	576.10	580.72
Jul	85	600.71	578.56	.60	1.05	576.21	580.80
Aug	84	600.88	578.50	.59	1.06	576.23	580.77
Sep	85	600.90	578.35	.58	1.04	576.16	580.57
Oct	82	600.83	578.14	.56	1.02	575.97	580.30
Nov	84	600.68	577.93	.58	1.02	575.76	580.11
Dec	70	600.45	577.75	.55	1.02	575.62	579.88

All values are in feet except for $\overline{Q}$ which is measured in thousands of cfs.

Source: University of Wisconsin 1975.

Note: Calculated from 1900-1973 data.

TABLE 10 MONTHLY OPERATING PARAMETERS FOR THE SO-901 MOD 7 REGULATION PLAN

Month	$\overline{Q}$	$\overline{S}$	$\overline{H}$	σ S	σ H	H Min.	H Max.
Jan	70	599.74	577.59	.75	.87	575.67	579.31
Feb	70	599.55	577.55	.74	.86	575.71	579.25
Mar	69	599.44	577.63	.78	.88	575.68	579.38
Apr	69	599.53	577.88	.78	.90	575.86	579.76
May	75	599.82	578.19	.77	.93	576.16	580.15
Jun	79	600.11	578.45	.78	.96	576.34	580.44
Jul	85	600.31	578.55	.80	.96	576.42	580.51
Aug	84	600.42	578.51	.80	.97	576.42	580.47
Sep	85	600.40	578.35	.80	.94	576.32	580.28
Oct	82	600.37	578.14	.78	.95	576.12	580.03
Nov	84	600.22	578.94	.77	.93	575.89	579.86
Dec	70	599.99	577.76	.75	.93	575.74	579.65

All values are in feet except for $\overline{Q}$ which is measured in thousands of cfs.

Source: University of Wisconsin 1975.

Note: Calculated from 1900-1973 data.

TABLE 11 MONTHLY OPERATING PARAMETERS FOR THE SO-901 MOD 8 REGULATION PLAN

Month	$\overline{Q}$	$\overline{S}$	$\overline{H}$	σS	σH	H Min.	H Max.
Jan	70	599.91	577.60	.78	.87	575.67	579.28
Feb	70	599.32	577.56	.79	.86	575.22	579.22
Mar	69	599.20	577.63	.83	.86	575.71	579.35
Apr	69	599.29	577.89	.82	.89	575.89	579.73
May	75	599.59	578.21	.81	.91	576.19	580.11
Jun	79	599.88	578.45	.82	.93	576.37	580.40
Jul	85	600.08	578.57	.84	.95	576.44	580.47
Aug	84	600.19	578.51	.85	.97	576.43	580.43
Sep	85	600.21	578.36	.84	.95	576.34	580.23
Oct	82	600.14	578.15	.82	.93	576.12	579.99
Nov	84	599.98	577.94	.80	.91	575.89	579.83
Dec	70	599.75	577.76	.79	.91	575.75	579.62

All values are in feet except for $\overline{Q}$ which is measured in thousands of cfs.

Source: University of Wisconsin-Madison 1975.

Note: Calculated from 1900-1973 data.

TABLE 12 LAKE SUPERIOR MINIMUM AND MAXIMUM OUTFLOW CONSTRAINTS

Month	Q Min.	Q Max.*
January	55	85
February	55	85
March	55	85
April	55	85
May	55	117
June	55	120
July	55	121
August	55	121
September	55	122
October	55	124
November	55	120
December	55	85

Source: IGLLB 1973, Main Report, pp. 269-270.

* cfs x thousand.

TABLE 13 PLOTTING POINTS GENERATED FROM THE LINEAR PROGRAM FOR SO-901 (1900-1973 DATA)

Month	(S Min.,	H Min.)	(S Max.,	H Max.)	Range
Jan	599.02 ,	575.54	601.34 ,	579.52	.15
Feb	598.74 ,	575.59	601.21 ,	579.45	.15
Mar	598.60 ,	575.48	601.09 ,	579.59	.15
Apr	598.63 ,	575.63	601.28 ,	579.98	.15
May	598.90 ,	575.91	601.72 ,	580.40	.31
Jun	599.11 ,	576.09	602.08 ,	580.72	.33
Jul	599.21 ,	576.20	602.17 ,	580.80	.33
Aug	599.47 ,	576.23	602.32 ,	580.77	.33
Sep	599.52 ,	576.16	602.32 ,	580.57	.34
Oct	599.50 ,	575.97	602.24 ,	580.30	.35
Nov	599.30 ,	575.76	602.09 ,	580.11	.33
Dec	599.22 ,	575.62	601.51 ,	579.58	.15

TABLE 14 PLOTTING POINTS GENERATED FROM THE LINEAR PROGRAM FOR SO-901 MOD 7 (1900-1973 DATA)

Month	(S Min.,	H Min.)	(S Max.,	H Max.)	Range
Jan	598.00 ,	575.67	601.30 ,	579.31	.15
Feb	597.89 ,	575.71	601.09 ,	579.25	.15
Mar	597.68 ,	575.68	601.03 ,	579.38	.15
Apr	597.71 ,	575.86	601.24 ,	579.76	.15
May	598.03 ,	576.16	601.65 ,	580.15	.31
Jun	598.27 ,	576.34	601.93 ,	580.44	.33
Jul	598.38 ,	576.42	602.12 ,	580.51	.33
Aug	598.55 ,	576.42	602.22 ,	580.47	.33
Sep	598.52 ,	576.31	602.23 ,	580.28	.34
Oct	598.57 ,	576.12	602.13 ,	580.03	.35
Nov	598.37 ,	575.88	601.99 ,	579.86	.33
Dec	598.32 ,	575.73	601.59 ,	579.65	.15

Note: All values are measured in units of feet.

TABLE 15 PLOTTING POINTS GENERATED FROM THE LINEAR PROGRAM FOR SO-901 MOD 8 (1900-1973 DATA)

Month	(S Min., H Min.)	(S Max., H Max.)	Range
Jan	597.70 , 575.67	601.09 , 579.28	.15
Feb	597.55 , 575.72	600.92 , 579.22	.15
Mar	597.27 , 575.71	600.94 , 579.35	.15
Apr	597.26 , 575.89	601.16 , 579.73	.15
May	597.69 , 576.19	601.49 , 580.11	.31
Jun	597.92 , 576.37	601.80 , 580.40	.33
Jul	597.99 , 576.44	601.88 , 580.47	.33
Aug	598.22 , 576.43	602.06 , 580.43	.33
Sep	598.27 , 576.34	602.05 , 580.23	.34
Oct	598.21 , 576.12	601.97 , 579.99	.35
Nov	598.03 , 575.89	601.82 , 579.83	.33
Dec	597.93 , 575.75	601.44 , 579.62	.15

Note: All values are measured in units of feet.

TABLE 16 PERCENTAGE OF THE HISTORICAL RECORD FOR WHICH THE SO-901 TYPE REGULATION PLANS ARE NOT LIMITED BY RULE CONSTRAINTS

Month	SO-901 %	Mod 7 %	Mod 8 %
Jan	28	34	38
Feb	31	38	32
Mar	32	41	42
Apr	27	34	36
May	42	51	49
Jun	45	34	51
Jul	46	39	62
Aug	53	54	51
Sep	54	57	54
Oct	61	54	51
Nov	42	41	53
Dec	38	35	31
74-Year Record (1900-1973)	41	43	46

TABLE 17 75TH PERCENTILE AVERAGE MONTHLY LEVELS FOR SO-901 AND MODS 7 AND 8 OF SO-901 — LAKE SUPERIOR

Month	SO-901	Mod 7	Mod 8
Jan	600.57	600.24	600.03
Feb	600.39	600.05	599.85
Mar	600.26	599.95	599.76
Apr	600.37	600.05	599.84
May	600.97	600.34	600.13
Jun	601.11	600.63	600.43
Jul	601.28	600.85	600.64
Aug	601.29	600.96	600.76
Sep	601.21	600.94	600.77
Oct	601.21	600.89	600.69
Nov	601.06	600.74	600.52
Dec	600.80	600.49	600.28

TABLE 18 75TH PERCENTILE AVERAGE MONTHLY LEVELS FOR SO-901 AND MODS 7 AND 8 OF SO-901 — LAKES MICHIGAN-HURON

Month	SO-901	Mod 7	Mod 8
Jan	578.23	578.17	578.18
Feb	578.18	578.12	578.13
Mar	578.26	578.22	578.21
Apr	578.53	578.48	578.49
May	578.88	578.81	578.82
Jun	579.13	577.09	579.07
Jul	579.26	577.19	579.21
Aug	579.21	579.16	579.16
Sep	579.05	578.98	579.00
Oct	578.82	578.78	578.77
Nov	578.61	578.56	578.55
Dec	578.43	578.38	578.37

Note: All values are measured in units of feet.

TABLE 19 HOW OFTEN SO-901 IS NOT LIMITED BY RULE CONSTRAINTS BEYOND THE 75TH PERCENTILE AVERAGE MONTHLY LEVELS

Month	Lakes Michigan-Huron %	Lake Superior %	Both %
Jan	36	26	35
Feb	29	25	36
Mar	29	23	33
Apr	7	8	11
May	19	36	33
Jun	18	36	29
Jul	43	47	50
Aug	46	50	61
Sep	48	55	65
Oct	73	65	76
Nov	40	42	43
Dec	40	26	29
Total	39	38	46

TABLE 20 HOW OFTEN THE MOD 7 PLAN IS NOT LIMITED BY RULE CONSTRAINTS BEYOND THE 75TH PERCENTILE AVERAGE MONTHLY LEVELS

Month	Lakes Michigan-Huron %	Lake Superior %	Both %
Jan	25	21	26
Feb	44	35	44
Mar	41	33	44
Apr	39	39	44
May	32	47	40
Jun	17	27	39
Jul	33	50	59
Aug	50	61	65
Sep	54	57	60
Oct	60	64	70
Nov	29	33	33
Dec	33	30	36
Total	39	41	46

TABLE 21 HOW OFTEN THE MOD 8 PLAN IS NOT LIMITED BY RULE CONSTRAINTS BEYOND THE 75TH PERCENTILE AVERAGE MONTHLY LEVELS

Month	Lakes Michigan-Huron %	Lake Superior %	Both %
Jan	36	30	38
Feb	44	35	44
Mar	39	33	41
Apr	31	29	38
May	35	47	50
Jun	42	45	50
Jul	67	62	72
Aug	44	50	53
Sep	48	53	55
Oct	52	65	72
Nov	56	62	65
Dec	30	23	29
Total	44	44	49

FIGURES 23-34 JOINT FREQUENCY DISTRIBUTION OF MEAN MONTHLY LAKE LEVELS FOR LAKES MICHIGAN-HURON VS LAKE SUPERIOR; AND, THE PARALLELOGRAM WITHIN WHICH THE REGULATION OF OUTFLOWS WOULD NOT BE LIMITED BY RULE CONSTRAINTS (1900-1973)

Figure 23 Plan SO-901 - January

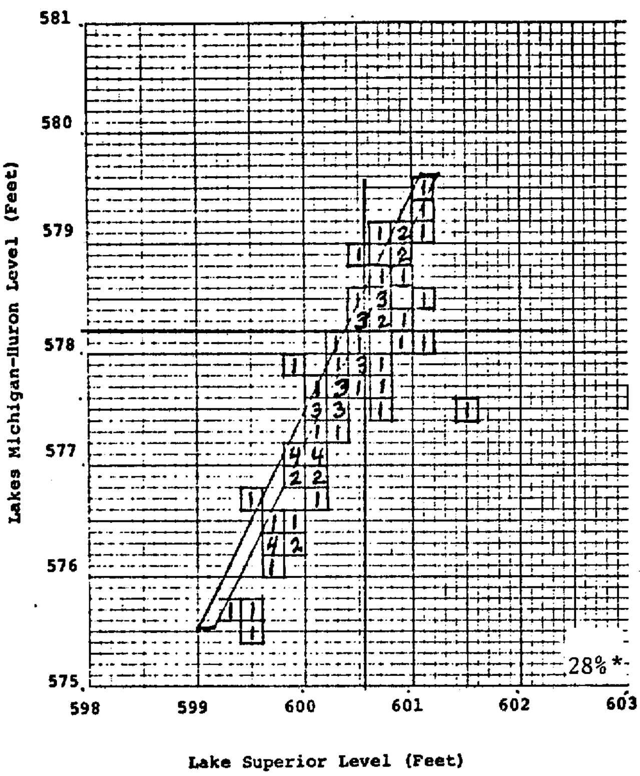
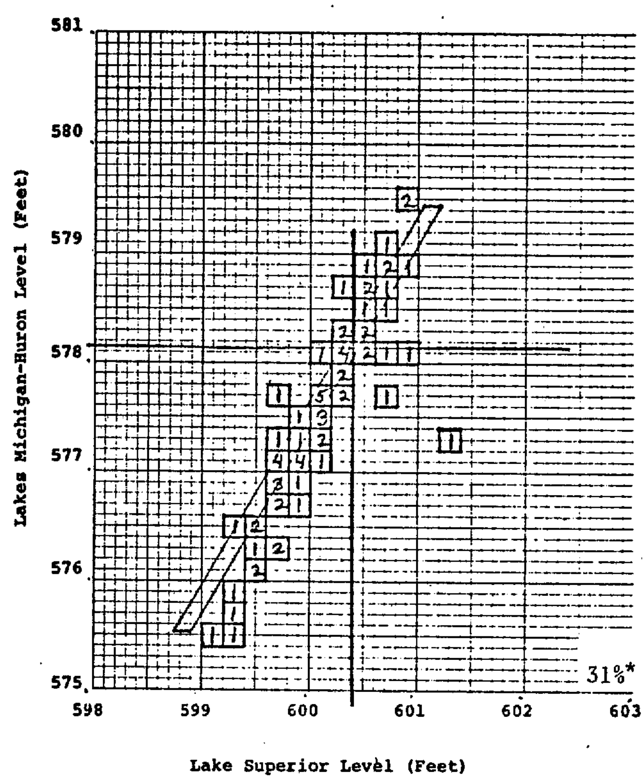


Figure 24 Plan SO-901 - February



Note: ——+—— = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 25 Plan SO-901 - March

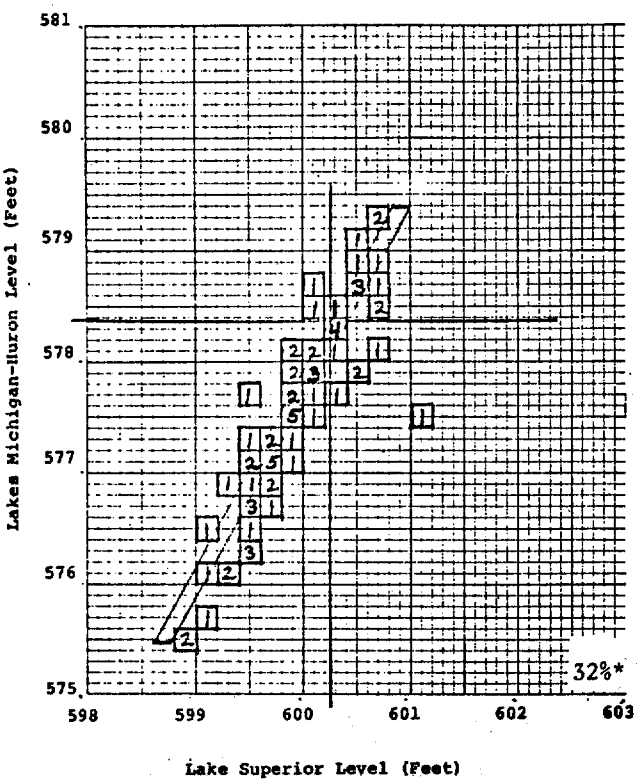
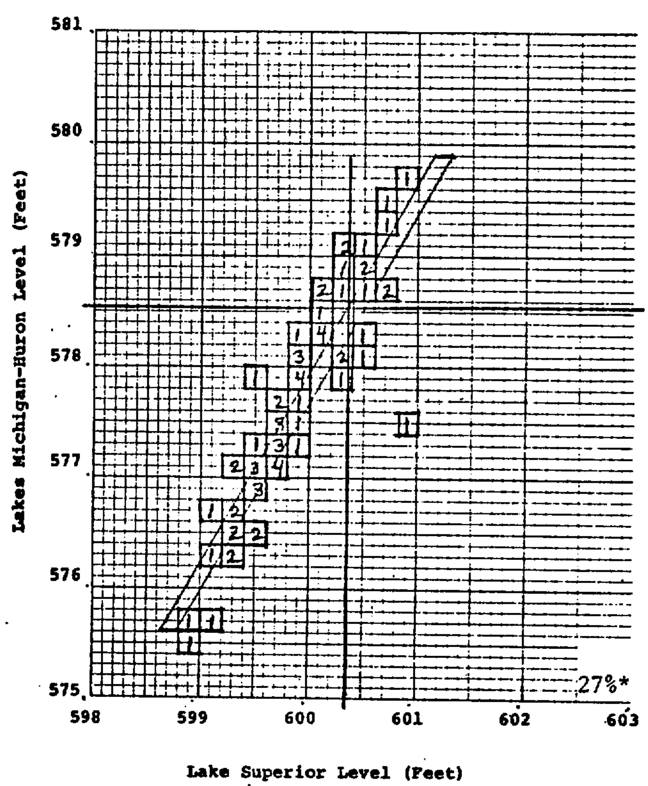


Figure 26 Plan SO-901 - April



Note: = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 27   Plan SO-901 - May

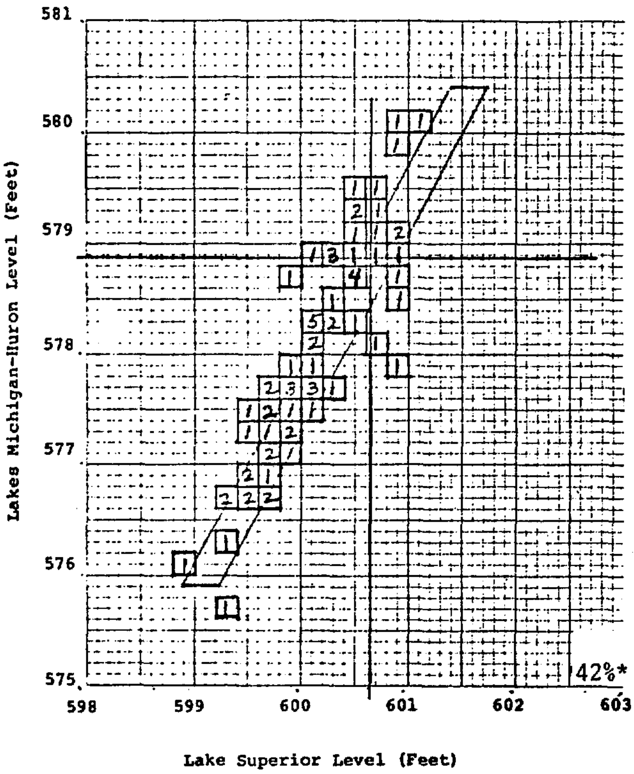
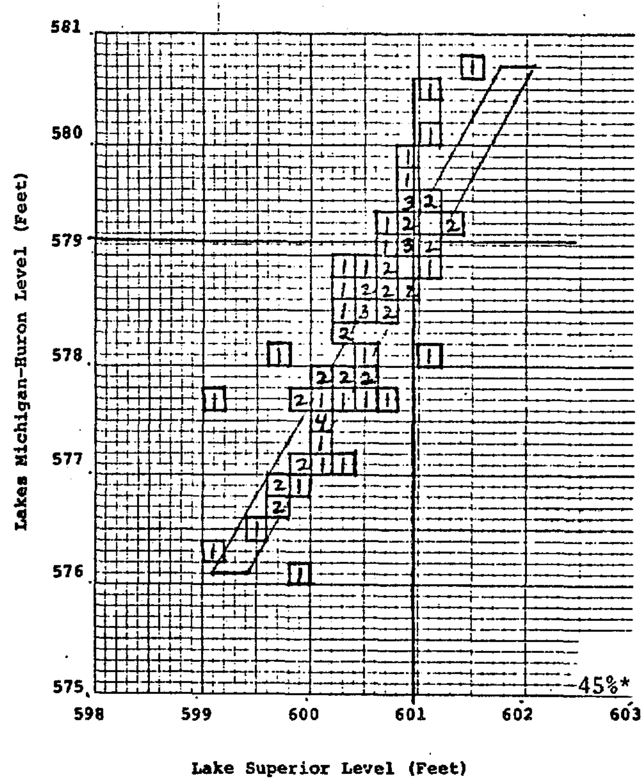


Figure 28   Plan SO-901 - June



Note: ┼ = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 29 Plan SO-901 - July

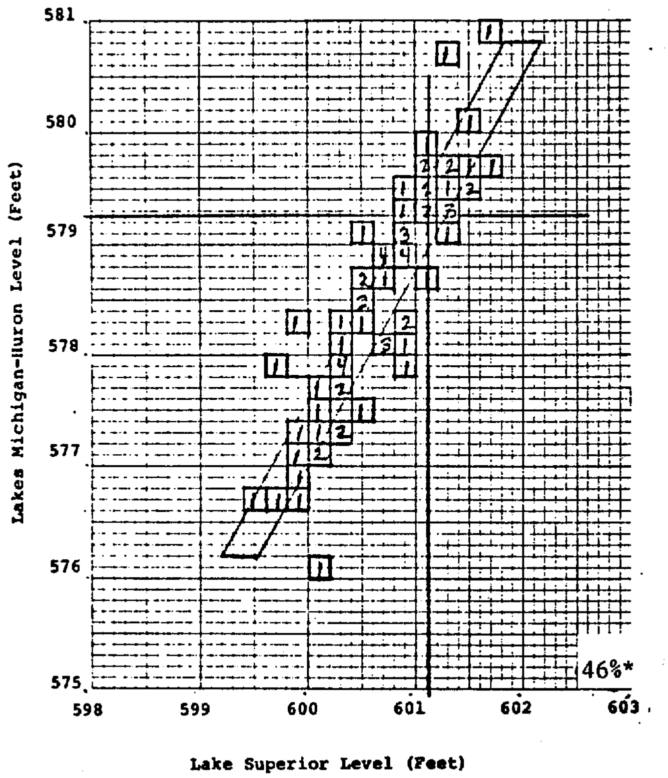
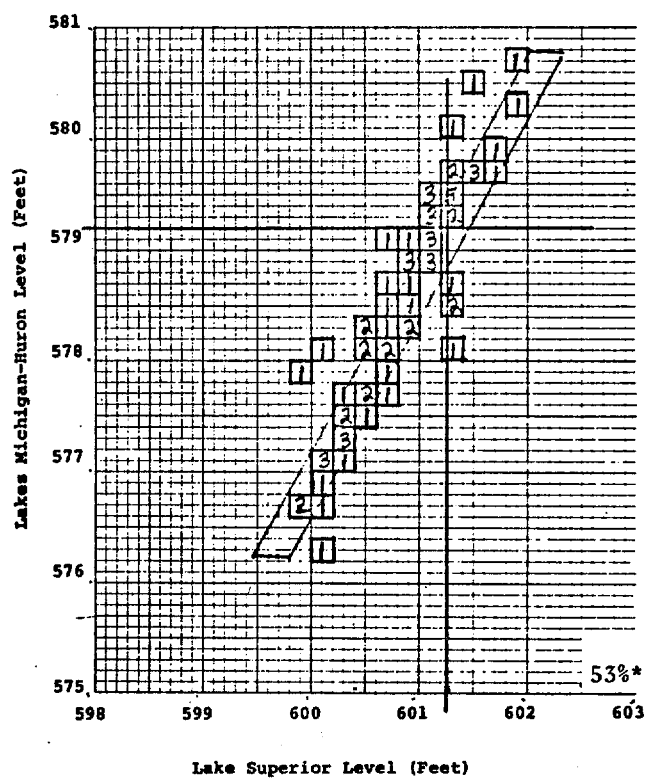


Figure 30 Plan SO-901 - August



Note: ┼ = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 31 Plan SO-901 - September

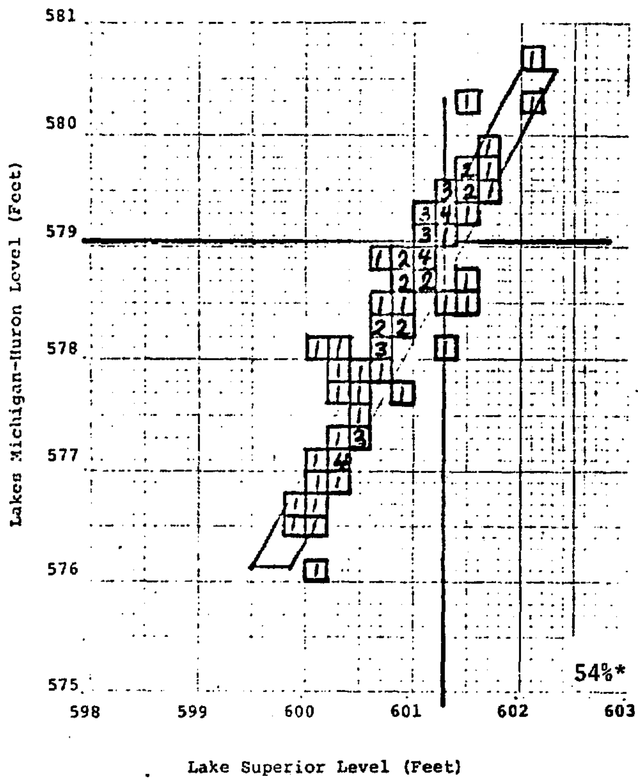
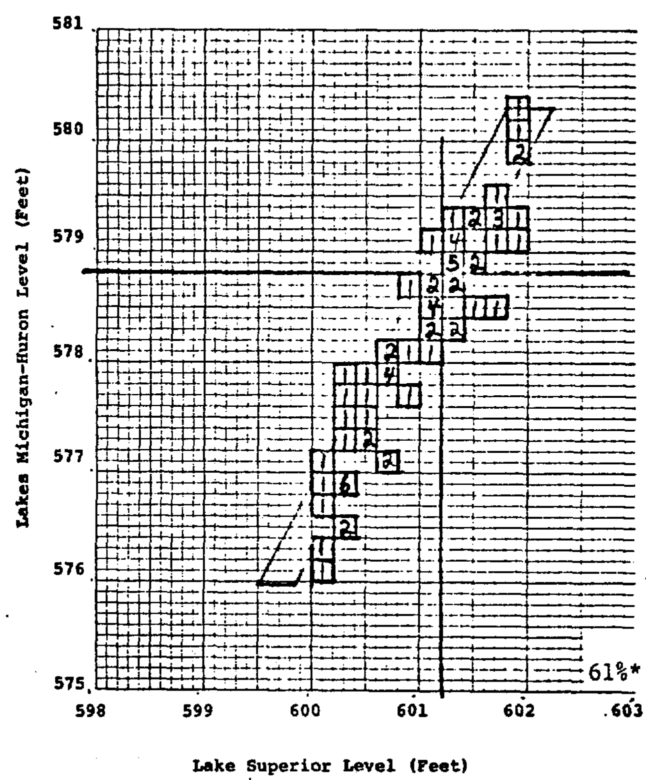


Figure 32 Plan SO-901 - October



Note: = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 33 Plan SO-901 - November

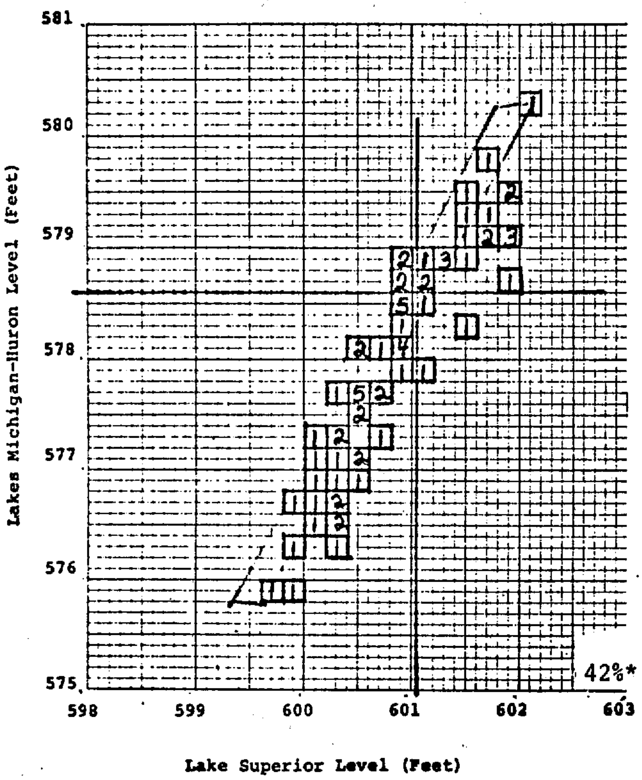
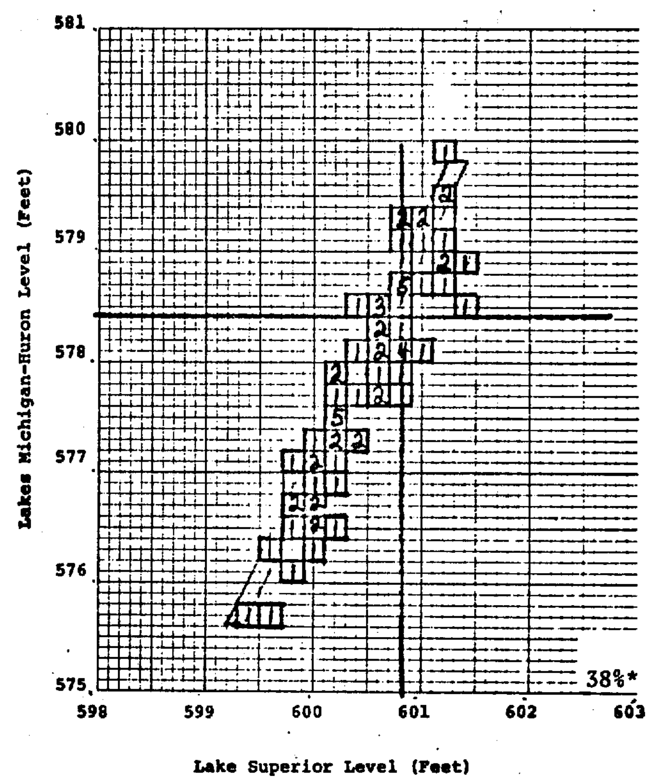
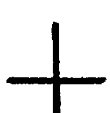


Figure 34 Plan SO-901 - December



Note:  = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

FIGURES 35-46 JOINT FREQUENCY DISTRIBUTION OF MEAN MONTHLY LAKE LEVELS FOR LAKES MICHIGAN-HURON VS LAKE SUPERIOR; AND, THE PARALLELOGRAM WITHIN WHICH THE REGULATION OF OUTFLOWS WOULD NOT BE LIMITED BY RULE CONSTRAINTS (1900-1973)

Figure 35 Plan SO-901 Mod 7 - January

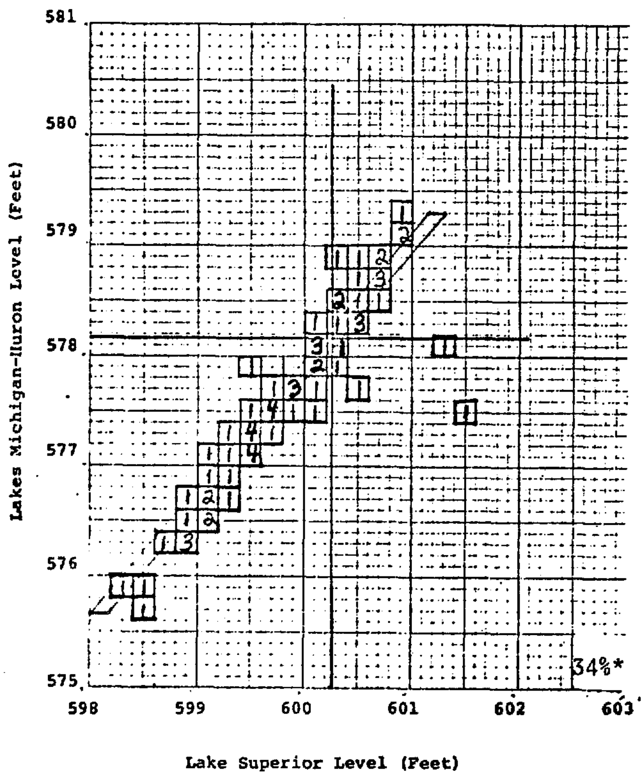
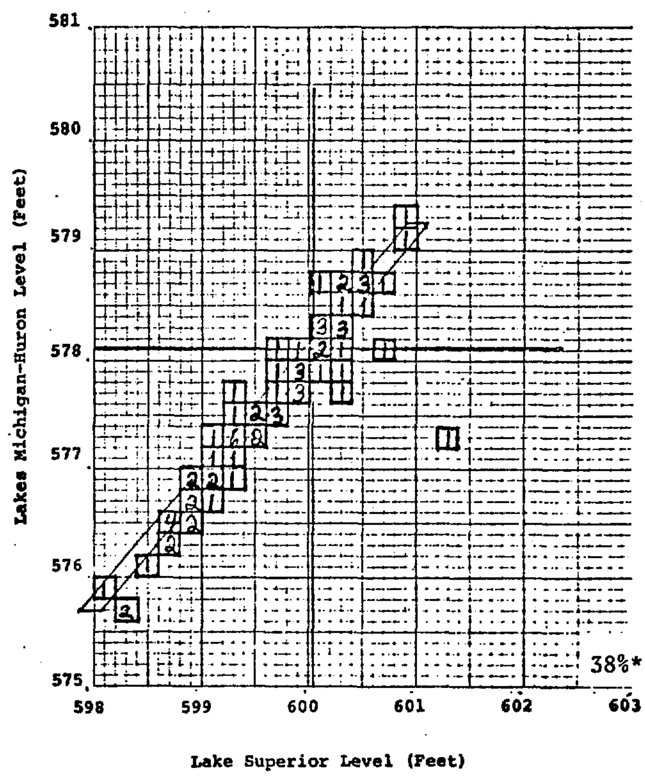


Figure 36 Plan SO-901 Mod 7 - February



Note: ┼ = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 37 Plan SO-901 Mod 7 - March

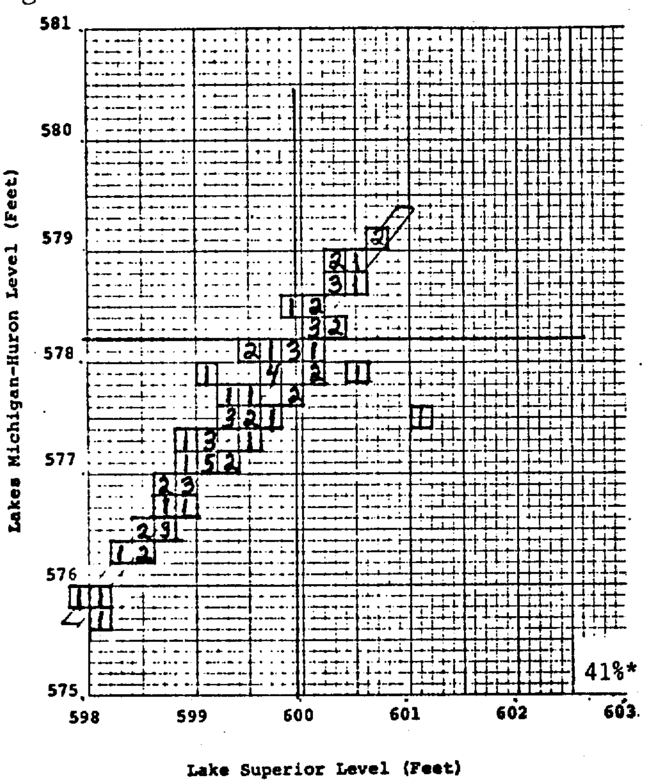
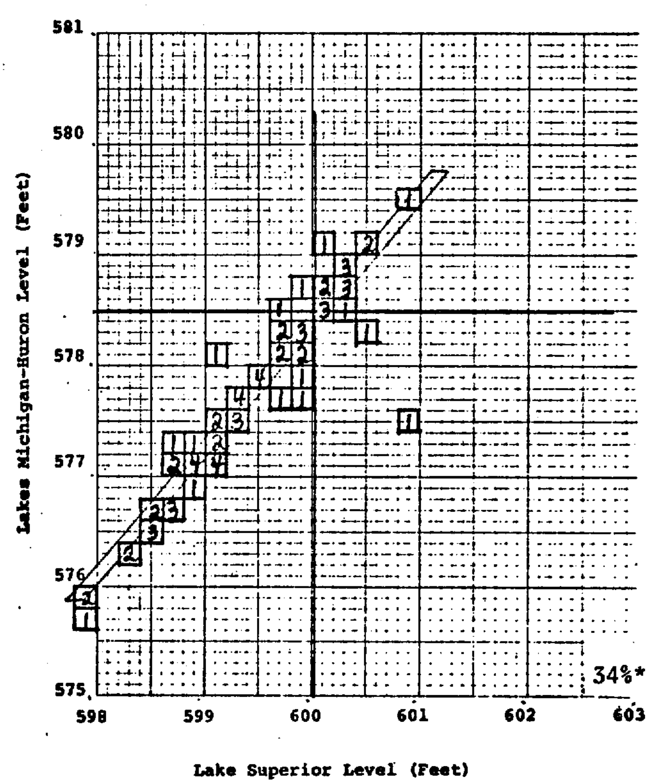


Figure 38 Plan SO-901 Mod 7 - April



Note: = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 39 Plan SO-901 Mod 7 - May

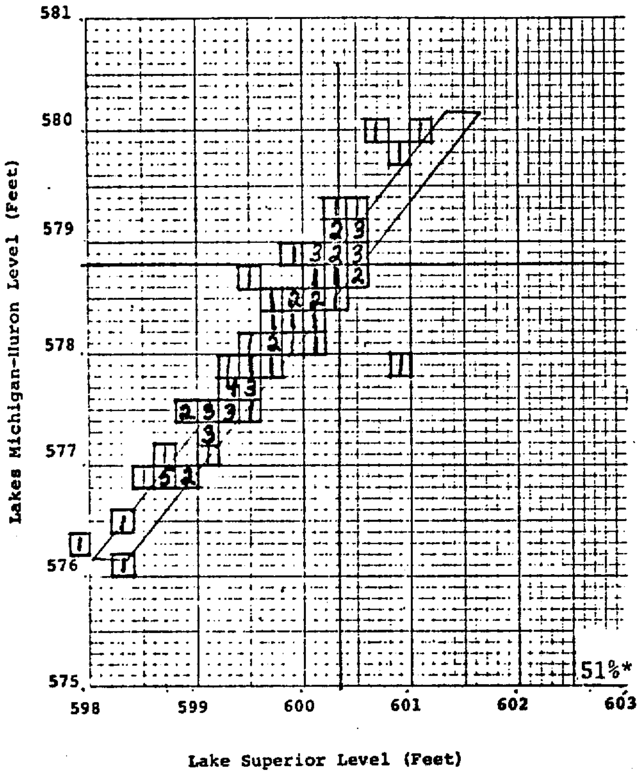
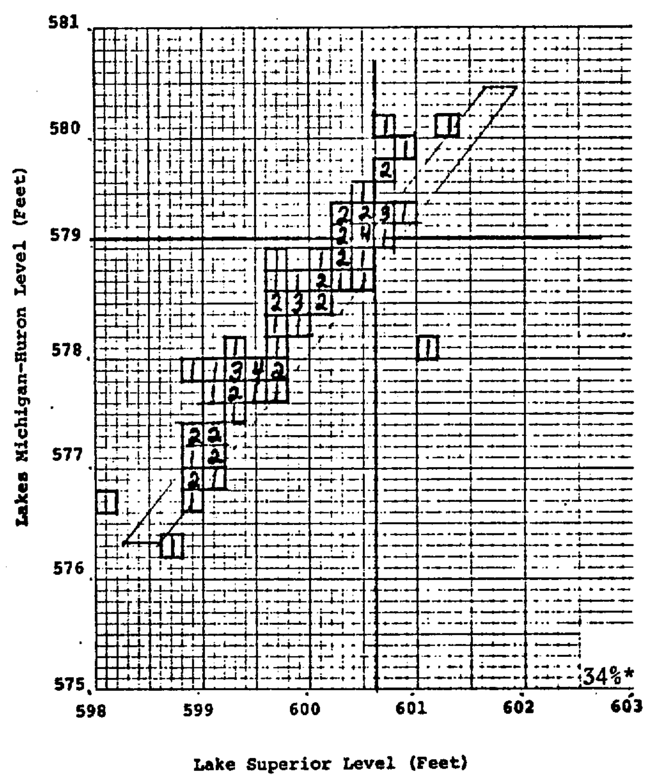


Figure 40 Plan SO-901 Mod 7 - June



Note: = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 41 Plan SO-901 Mod 7 - July

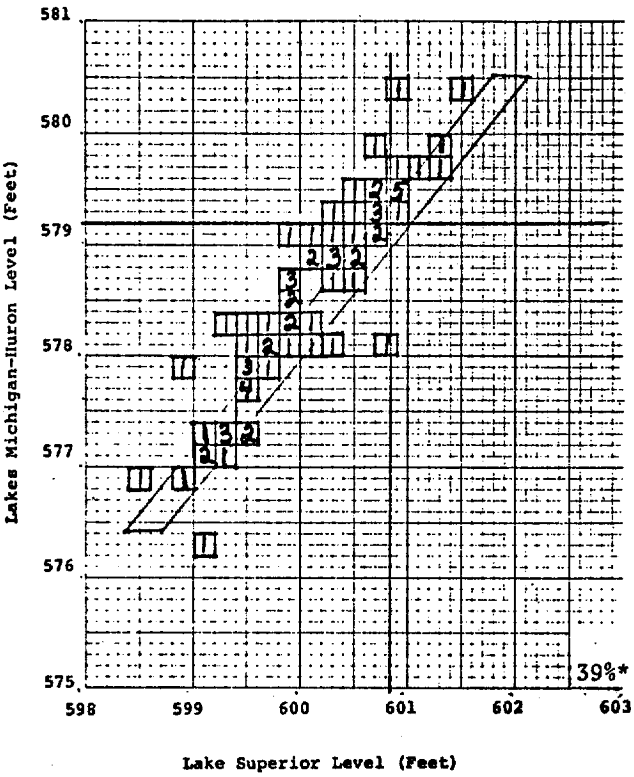
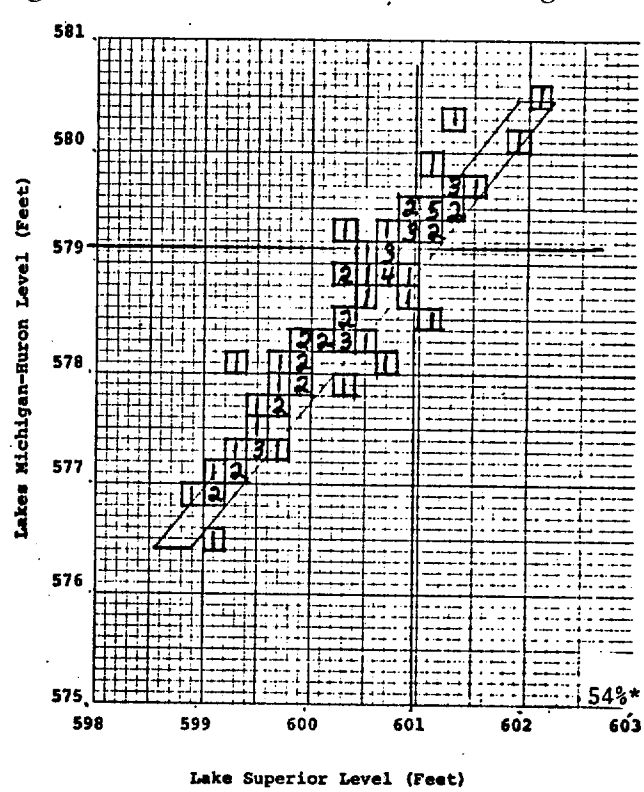


Figure 42 Plan SO-901 Mod 7 - August



Note: ✛ = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 43 Plan SO-901 Mod 7 - September

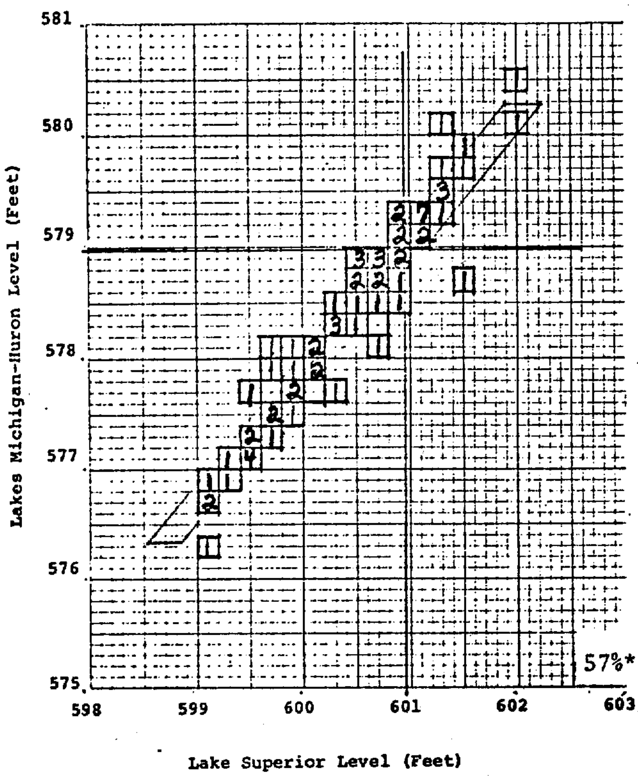
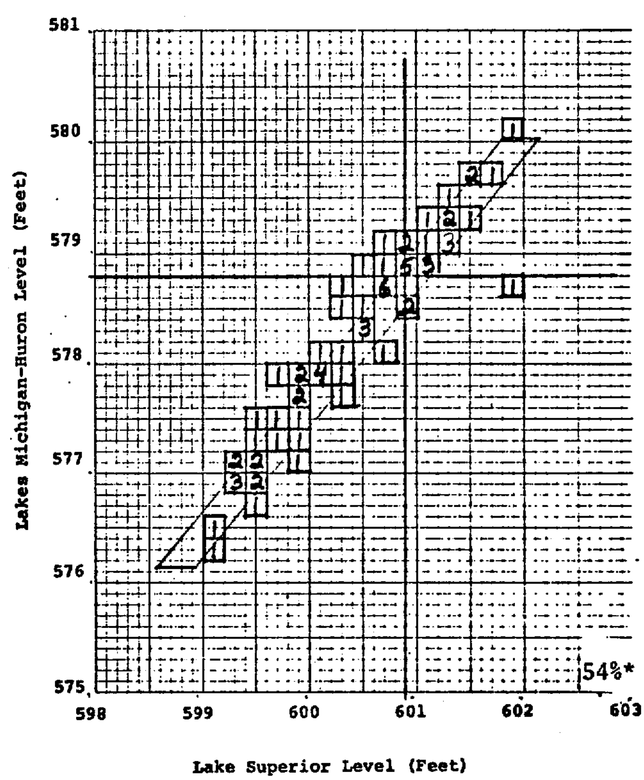


Figure 44 Plan SO-901 Mod 7 - October



Note: [cross symbol] = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 45 Plan SO-901 Mod 7 - November

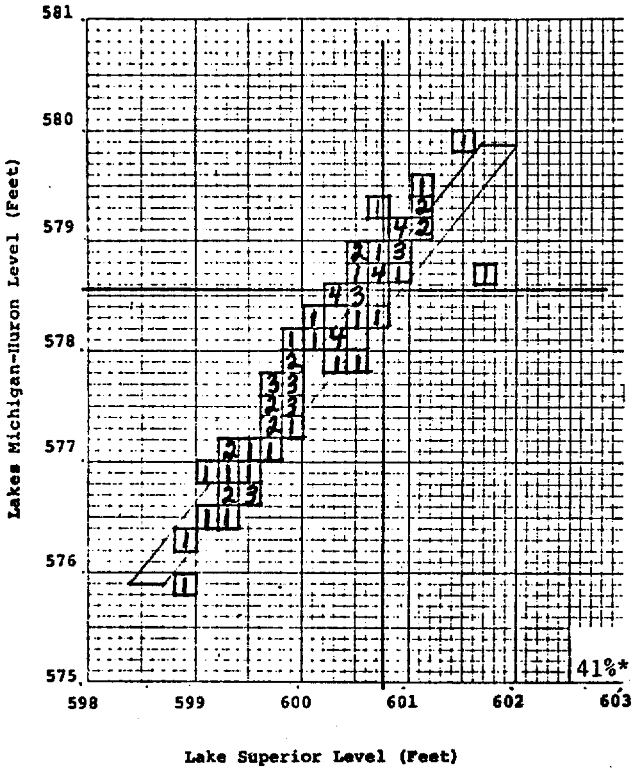
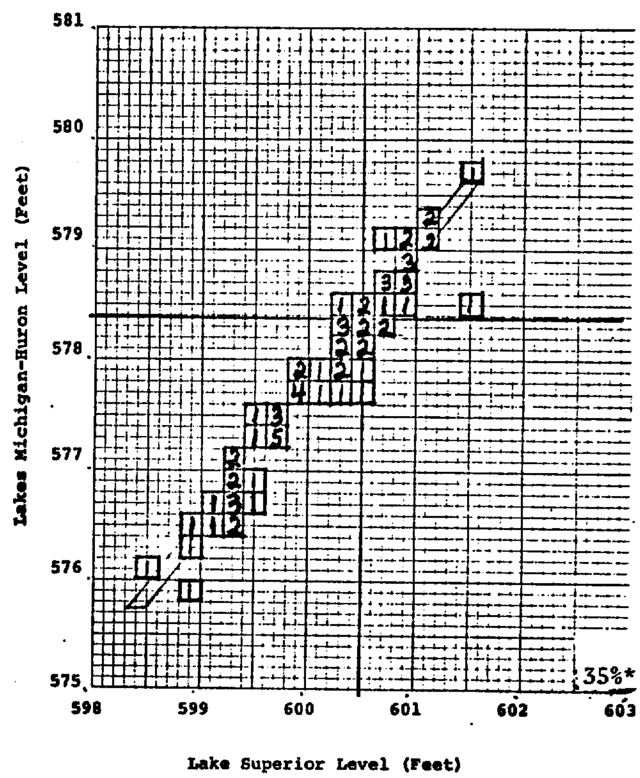


Figure 46 Plan SO-901 Mod 7 - December



Note: ![] = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

FIGURES 47-58 JOINT FREQUENCY DISTRIBUTION OF MEAN MONTHLY LAKE LEVELS FOR LAKES MICHIGAN-HURON VS LAKE SUPERIOR; AND, THE PARALLELOGRAM WITHIN WHICH THE REGULATION OF OUTFLOWS WOULD NOT BE LIMITED BY RULE CONSTRAINTS (1900-1973)

Figure 47 Plan SO-901 Mod 8 - January

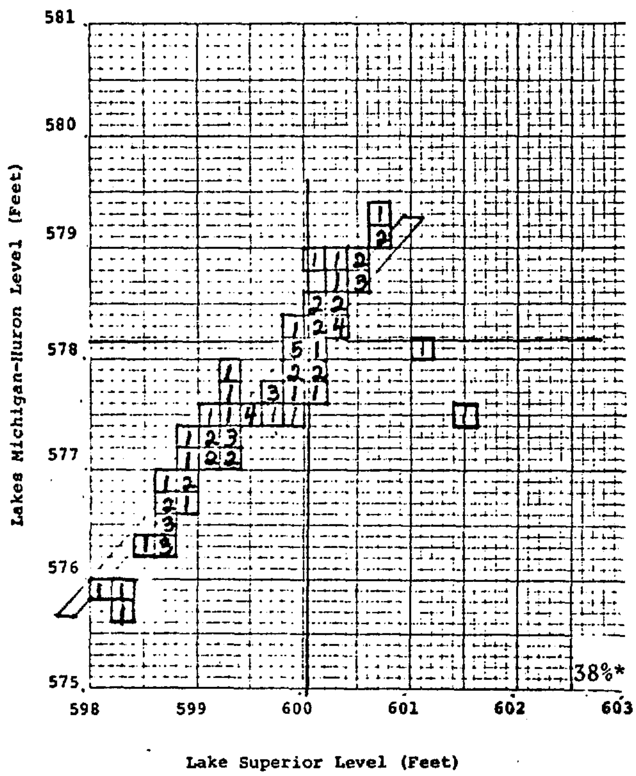
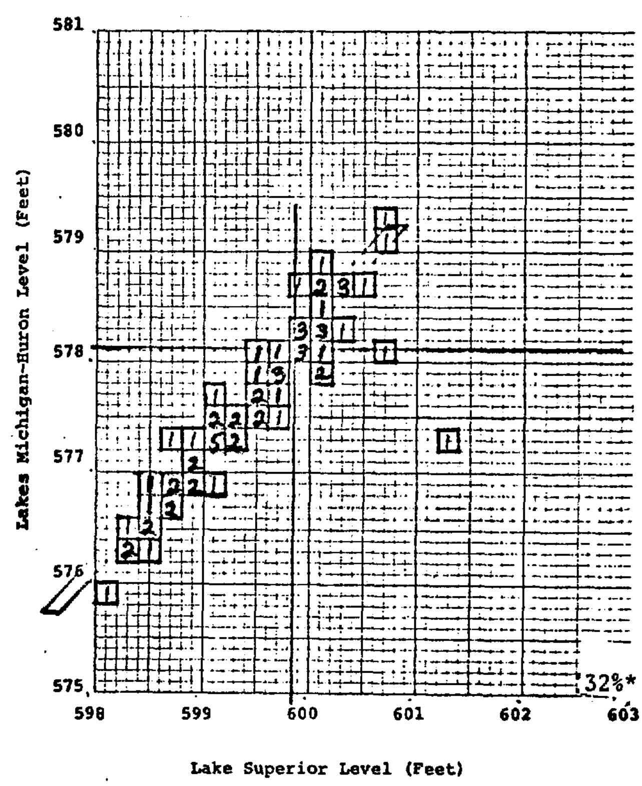


Figure 48 Plan SO-901 Mod 8 - February



Note: = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 49 Plan SO-901 Mod 8 - March

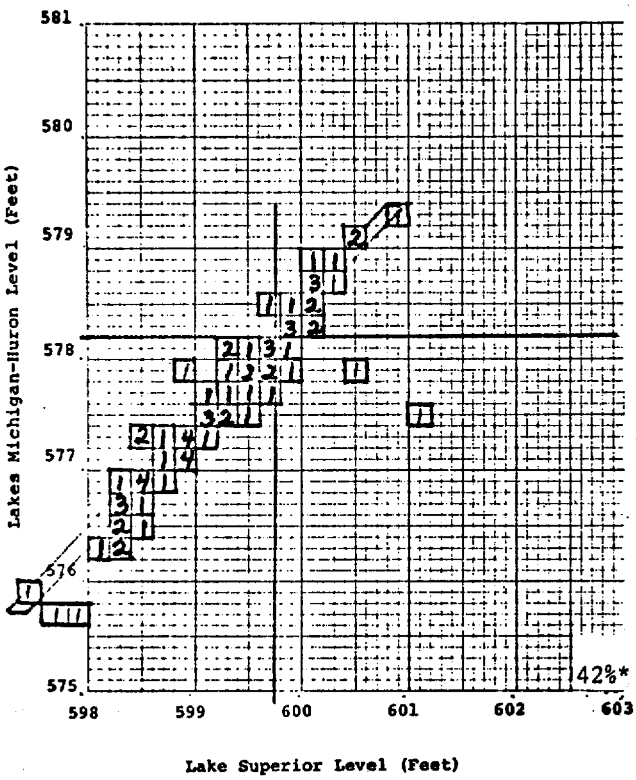
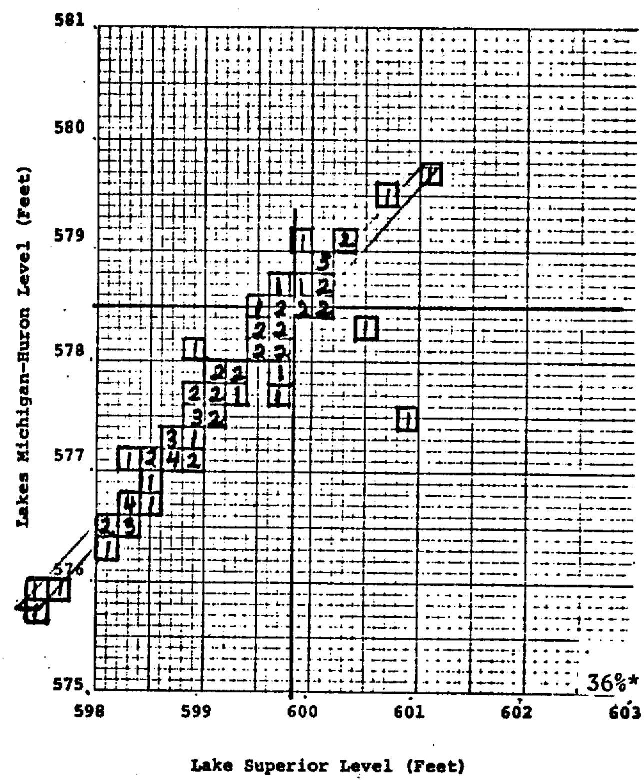


Figure 50 SO-901 Mod 8 - April



Note: = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 51 Plan SO-901 Mod 8 - May

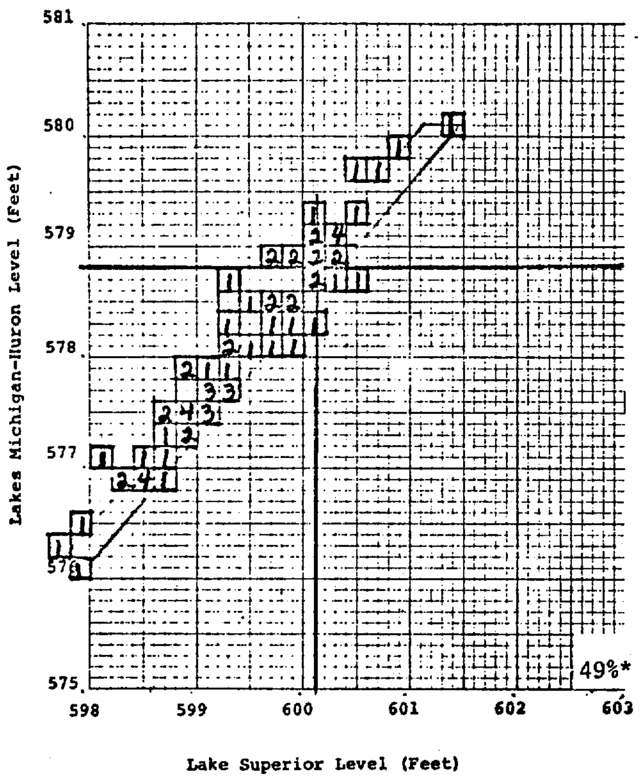
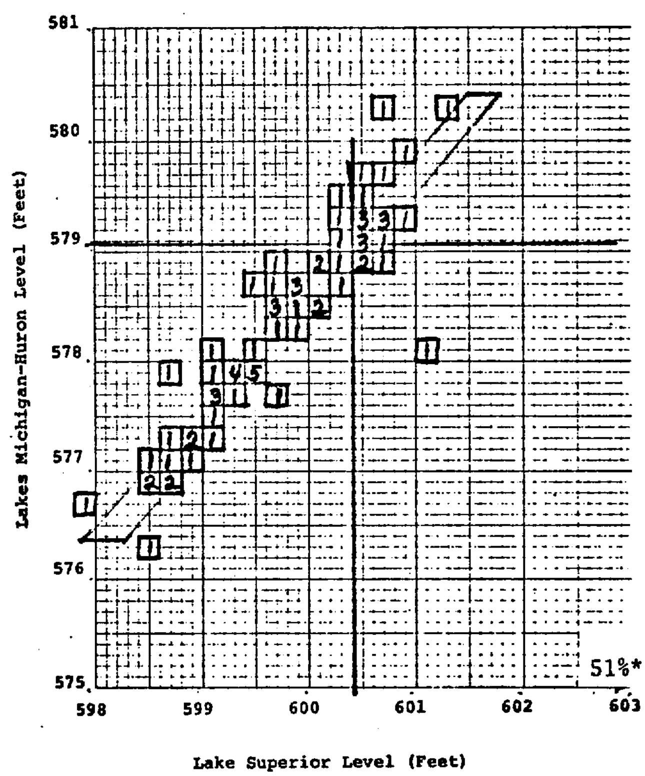


Figure 52 Plan SO-901 Mod 8 - June



Note: = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 53 Plan SO-901 Mod 8 - July

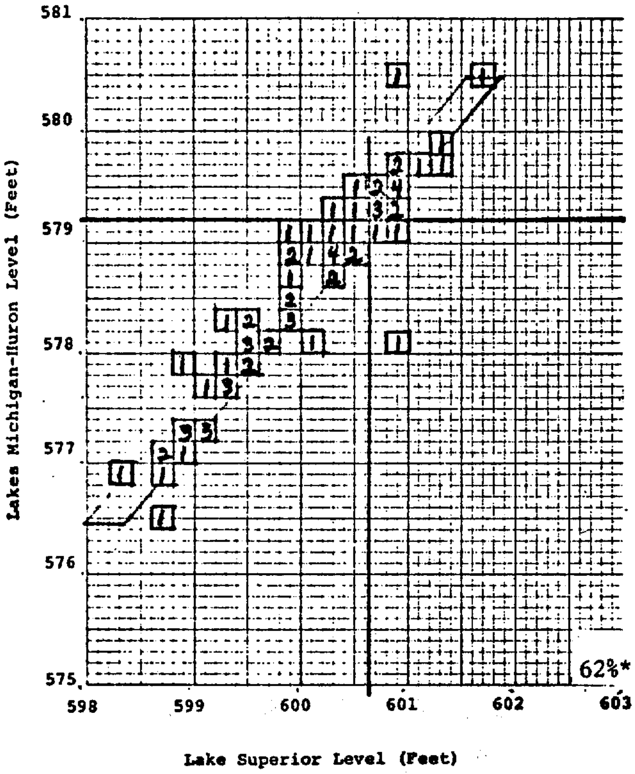
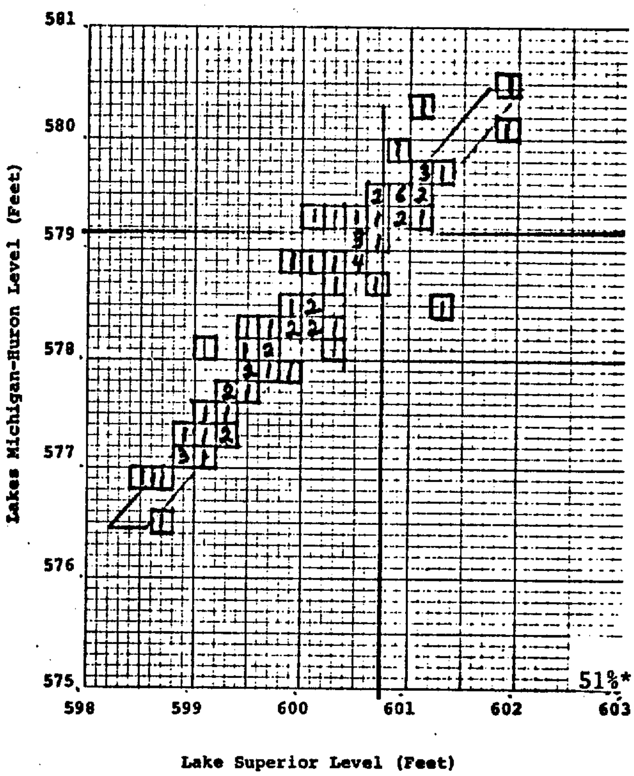
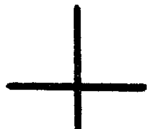


Figure 54 Plan SO-901 Mod 8 - August



Note:  = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 55 Plan SO-901 Mod 8 - September

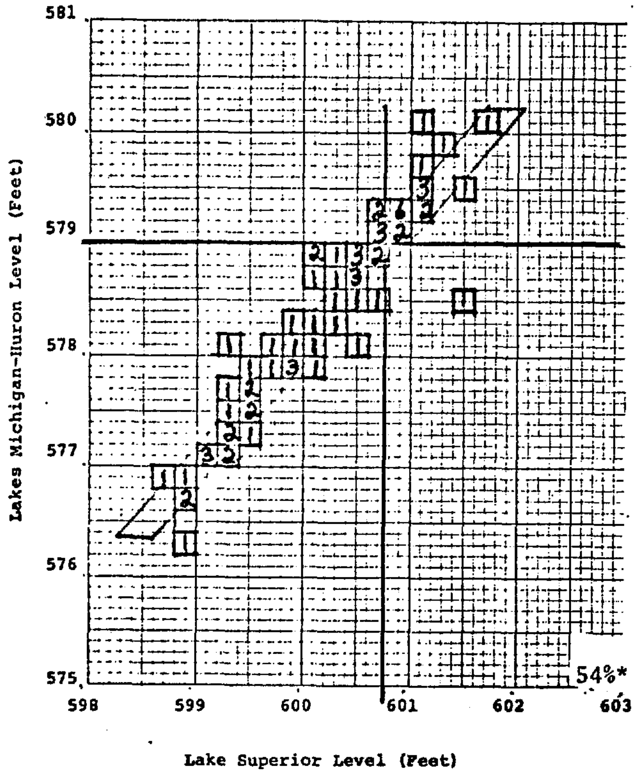
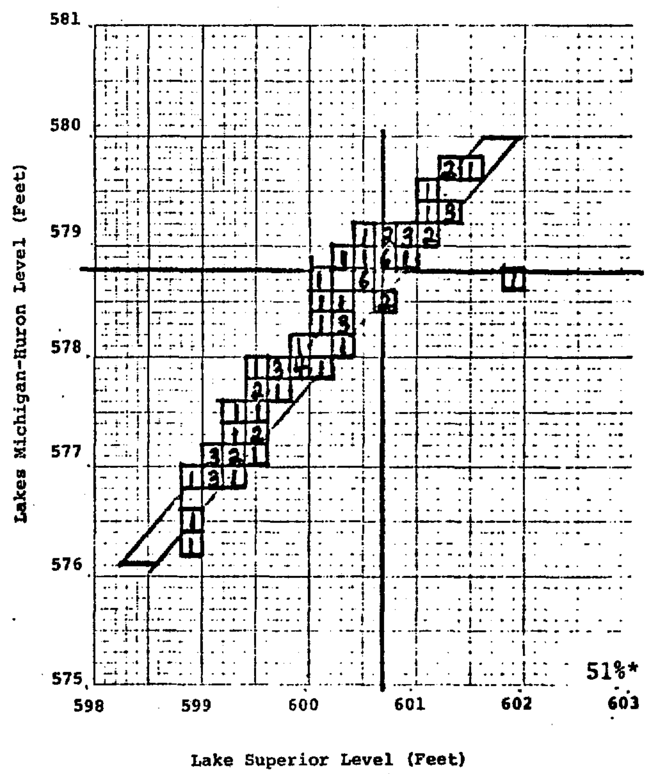


Figure 56 Plan SO-901 Mod 8 - October



 Note: = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

Figure 57 Plan SO-901 Mod 8 - November

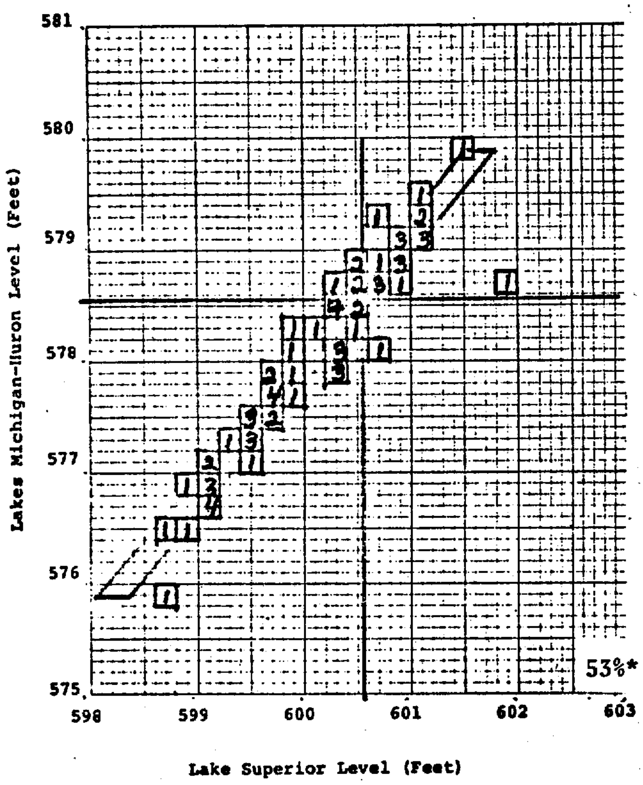
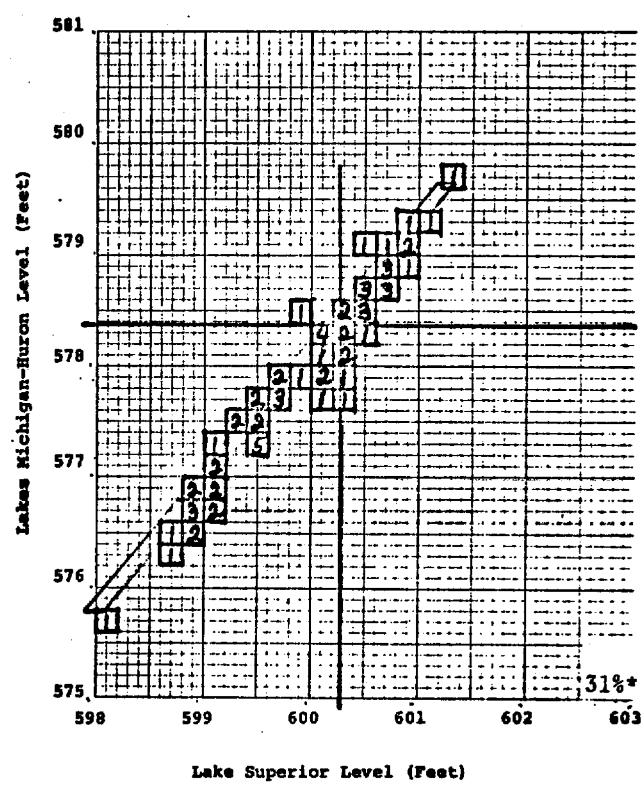


Figure 58 Plan SO-901 Mod 8 - December



Note: [crossed lines symbol] = 75th percentile average monthly levels.

*Percent of time that regulation is fully operative.

A secondary consideration in this study was to evaluate the efficiency of the regulation rule during high supply periods. This was accomplished by analyzing the effectiveness of the plans at lake levels greater than the 75th percentile level. These data were obtained from the joint distribution of average monthly levels of the two lakes based upon the computer simulation data using 1962 outlet conditions for Lake Huron. For high levels on Lake Superior the release rule for Plans SO-901, and Mods 7 and 8 of SO-901 would have been fully operational for 38%, 41%, and 44%, respectively, of the historical record. In the case of Lakes Michigan-Huron the rule for the three plans is operational 39%, 39%, and 44% of the time. For the occurrence where both lake levels were greater than the 75th percentile the plans are operational 46%, 46%, and 49% of the time.

Interestingly, the IGLLB (Main Report, p. 137) stated that ". . .high levels generally occur at the same time on all the lakes. Any attempt to increase Lake Superior maximum flows during periods of high water supply would cause greater damage to the lower lakes." The results of this study indicate that this is not necessarily the case. Table 22 lists for each lake the percentage of the historical record for which mean monthly levels (from the Basis-of-Comparison data) were greater than the 75th percentile level and also the percentage of the record for which levels on the two lakes were simultaneously greater than the 75th percentile level. According to these results Lakes Superior and Michigan-Huron are simultaneously high as defined by the 75th percentile criterion, less than one-half as often as either lake is high. Apparently this discrepancy is due to a time lag in the response of Lakes Michigan-Huron to high levels on Lake Superior and the relatively large volumes of the two lakes compared to the outflow capacity in the St. Marys River.

TABLE 22 PERCENT OF TIME THAT LAKES SUPERIOR AND MICHIGAN-HURON LEVELS ARE HIGH AND THE PERCENT OF TIME THAT LEVELS ON BOTH LAKES ARE SIMULTANEOUSLY HIGH

Month	% of Historical Record for Which Lake Superior Level ≥ 75th Percentile	% of Historical Record for Which Lakes Michigan-Huron Level ≥ 75th Percentile	% of Historical Record for Which Both Lake Levels ≥ 75th Percentile
Jan	19	31	9
Feb	19	36	10
Mar	27	37	13
Apr	37	43	18
May	51	42	24
Jun	43	45	16
Jul	39	37	19
Aug	25	31	12
Sep	22	31	10
Oct	22	30	12
Nov	22	30	12
Dec	19	30	10
74-Year Record (1900-1973)	29	35	14

Table 23 lists, by month, the plan that has the highest percentage of time characterized by unrestricted operation. The data of the table indicate that in 10 of the 12 months, one or the other of the SO-901 Mod plans had the highest operating percentage. Table 24 presents, on a monthly basis, the plan that has the highest percentage of time characterized by unrestricted operation for lake stages which exceed the 75th percentile. As above, one or the other of the SO-901 Mod plans had the highest percentage of time for unconstrained operation in 10 of the 12 months. Although the Mod plans of SO-901 appear to be more effective than Plan SO-901 in the regulation of water levels on Lakes Superior and Michigan-Huron, it may be recalled that a principal disadvantage of the Mod plans is the required dredging of the Lake Superior harbors as well as dredging in parts of the St. Marys River. Dredging costs reduce the benefits of the Mod plans.

TABLE 23 PLAN THAT IS LEAST CONSTRAINED BY RULE LIMITATIONS FOR EACH MONTH

Month	Plan	Percentage
Jan	Mod 8	38
Feb	Mod 7	38
Mar	Mod 8	42
Apr	Mod 8	36
May	Mod 7	51
Jun	Mod 8	51
Jul	Mod 8	62
Aug	Mod 7	54
Sep	Mod 7	57
Oct	SO-901	61
Nov	Mod 8	53
Dec	SO-901	38

TABLE 24 PLAN THAT IS LEAST CONSTRAINED BY RULE LIMITATIONS FOR EACH MONTH WHEN BOTH LAKES ARE SIMULTANEOUSLY HIGH (≥ 75TH PERCENTILE LEVELS)

Month	Plan	Percentage
Jan	Mod 8	38
Feb	Mods 7, 8	44
Mar	Mod 7	44
Apr	Mod 7	44
May	Mod 8	50
Jun	Mod 8	50
Jul	Mod 8	72
Aug	Mod 7	65
Sep	SO-901	65
Oct	SO-901	76
Nov	Mod 8	65
Dec	Mod 7	36

In summary, the regulation of water levels on Lakes Superior and Michigan-Huron is often partially restricted by limitations set forth in the rules of regulation which have been designed to prevent damages to lake interests elsewhere in the Great Lakes. Because of the rule restrictions, the SO regulation plans do not accomplish the objective of balancing lake levels as close to their long-term mean magnitudes as often and as efficiently as might be desired. The annual average percentages of unrestricted operation of Plan SO-901, and Mods 7 and 8 of Plan SO-901, are 41%, 43%, and 46%, respectively. These modest percentages support the contention that climate remains as the dominant factor causing lake level related problems.

Although climate remains as the principal cause of large magnitude departures of lake levels from average, the data presented in this section of the report indicate that, despite the limitations on the fraction of time that regulation plans may be operated at full capacity, regulation significantly impacts the variability of lake levels. The reader may recall that the effects of "SO" regulation on Lake Superior tends to reduce the incidence of lake levels which fell in the modal range of the BOC data base relative to increase frequencies of occurrences of levels in the tails of the probability distributions of levels. For Lakes Michigan-Huron, the reader may also recall that the impact of "SO" regulation was somewhat more consistent with the objective of confining the range of lake levels to magnitudes which were closer to the long-term mean magnitude of the BOC data base. The results of this section of the report explain why there are only modest differences between lake level probabilities of Plan SO-901 and the BOC as described in the preceding unit of section IV. Since differences between long-term mean lake levels differ little between regulation according to SO-901 vs. the BOC, it can be inferred that the principal hydrologic impacts of regulation must be related to small adjustments in return frequencies of lake level magnitudes associated with the tails of the probability distributions of the levels. The significance of Plan SO-901, Mods 7 and 8 of Plan SO-901, and Plans SEO-42P and SEO-17P to affect the occurrence of lake levels in the extreme ranges of the probability distributions of lake levels is examined in the next section.

4. Effects of Regulation Plans on the Incidence of Extreme Levels

Negative impacts of lake level variations are generally associated with incidences of levels which represent large departures from the average, that is, above or below the long-term mean level. It has been shown in the preceding discussion that the general design of the "SO" regulation plans calls for minimizing variations of lake levels on Lakes Superior, Michigan, and Huron relative to their long-term means. The regulation plans are all also designed to preserve the average (long-term) patterns of seasonal fluctuation in levels. The conservative nature of the regulation schemes results in very small differences between the long-term mean lake levels for the BOC regulation versus long-term mean lake levels for regulation Plans SO-901, SEO-42P, and SEO-17P (Table 25). Mods 7 and 8 of Plan SO-901 also tend to preserve existing long-term patterns of seasonal fluctuations, but regulation for these two plans requires reductions in the long-term mean levels of Lake Superior (Table 25).

TABLE 25 SUMMARY OF RANGES OF STAGE AND ECONOMIC EVALUATION

MEAN MONTHLY LAKE LEVELS (FEET ABOVE SEA LEVEL—IGLD) 1900-1973

	Basis-of-Comparison	SO-901	SO-901 Mod 7	SO-901 Mod 8	SEO-42P	SEO-17P
LAKE SUPERIOR						
Mean	600.41	600.46	599.99	599.76	600.41	600.38
Max	601.91	602.00	602.08	601.93	601.95	601.92
Min	598.36	598.80	597.89	597.59	598.76	598.73
Range	3.55	3.20	4.19	4.34	3.19	3.19
Standard Deviation	0.65	0.67	0.86	0.89	0.67	------
LAKES MICHIGAN-HURON*						
Mean	578.04	578.04	578.05	578.05	577.94	577.87
Max	581.23	580.80	580.51	580.47	580.67	580.52
Min	575.12	575.48	575.67	575.67	575.39	575.35
Range	6.11	5.32	4.84	4.80	5.28	5.17
Standard Deviation	1.19	1.07	0.99	0.98	1.06	------
LAKE ERIE						
Mean	570.69	570.69	570.62	570.63	570.43	570.30
Max	573.75	573.53	572.90	572.82	573.19	572.97
Min	567.97	568.13	568.21	568.25	567.97	567.91
Range	5.78	5.40	4.69	4.57	5.22	5.06
Standard Deviation	1.03	0.97	------	------	0.93	------
LAKE ONTARIO						
Mean	244.57	244.54	244.56	244.56	244.51	244.40
Max	249.27	247.90	246.89	246.89	247.92	247.48
Min	240.82	241.48	241.92	242.13	241.13	241.41
Range	8.45	6.42	4.97	4.76	6.79	6.07
Standard Deviation	1.05	0.92	------	------	0.96	------
APPROXIMATE ANNUAL BENEFITS ($ MILLIONS)**						
Power	0.0	+ 0.64	+ 0.6	+ 0.9	+ 0.00	- 0.52
Navigation***	0.0	+ 0.93	+ 2.9	+ 2.0	+ 0.63	+ 0.29
Shore Property	0.0	+ 0.73	+ 2.7	+ 3.1	+ 7.74	+ 9.77
TOTAL	0.0	+ 2.30	+ 6.2	+ 6.0	+ 8.37	+ 9.54
GEOGRAPHICAL BREAKDOWN OF SHORE PROPERTY BENEFITS ($ MILLIONS)						
Superior	0.0	- 0.12	+ 1.2	+ 1.5	+ 0.15	+ 0.30
Michigan-Huron	0.0	+ 0.42	+ 1.2	+ 1.3	+ 2.39	+ 3.13
Erie	0.0	+ 0.46	+ 0.2	+ 0.2	+ 4.00	+ 4.80
Ontario	0.0	- 0.03	+ 0.1	+ 0.1	+ 1.20	+ 1.54
TOTAL	0.0	+ 0.73	+ 2.7	+ 3.1	+ 7.74	+ 9.77

Sources: U.S. Army Corps of Engineers 1974.
University of Wisconsin-Madison 1975.
IGLLB 1973, Main Report.

Notes:
* 1962 outlet conditions.
** Average annual benefits for the BOC and all plans except SEO-17P were calculated by the Levels Board for 1900-1967 levels. Benefits from Plans SO-901 and SEO-42P and shore benefits from SEO-17P calculated with detailed analysis. Other economic effects calculated with generalized loss curves. Shore property benefits from SEO-17P are to U.S. shores only.
*** Navigation benefits are computed for traffic routes, not for individual lakes.

Tables 26 and 27 compare the differences between monthly means and standard deviations of lake levels for Lakes Superior and Michigan-Huron under BOC regulation versus regulation according to Plans SO-901, Mods 7 and 8 of SO-901, and SEO-42P. The data of Tables 26 and 27 indicate that the effects of lake level regualtion on means and standard deviations of lake levels are approximately the same regardless of the month of the year. The data reveal that significant reductions in Lake Superior mean levels are only produced by the Mod plans of SO-901 and that "SO" regulation has little effect on long-term mean levels of Lakes Michigan and Huron. Tables 26 and 27 also confirm the charge that the "SO" regulation plans slightly increase the standard deviation of levels on Lake Superior and decrease the standard deviation of levels on Lakes Michigan and Huron.

Despite the relatively conservative characteristics of the proposed regulation plans, estimates of economic impacts suggest that substantial effects are produced (Table 25). A large portion of the benefits and/or damages attributed to lake level regulation relate to the effects of the plans on levels which represent major departures from the mean.

The relative impacts of Plan SO-901, Mods 7 and 8 of Plan SO-901, SEO-42P and SEO-17P to influence extremes of high lake levels were investigated by the University study group and the results are presented in Tables 28-31. Estimation of the effects of regulation on occurrence of extreme high levels was accomplished by tallying the frequencies of levels above specified datums of 601.4 feet for Lake Superior and 579.6 feet for Lakes Michigan and Huron.*

Inspection of Tables 28 and 29 indicates that the impacts of regulation on extreme high lake levels are relatively modest. For Lake Superior, the number of levels during the period 1900-1973 which would have exceeded 601.4 feet are 27 for the BOC regulation, but would increase to 46 and 37 in number, respectively, for Plans SO-901 and SEO-42P. Regulation of Lake Superior water levels under Mods 7 and 8 of SO-901, however, would reduce the number of occurrences of levels exceeding 601.4 feet to only 18 for Mod 7 and 12 for Mod 8. For Lakes Michigan and Huron, the number of levels during the period 1900-1973 which would have exceeded 579.6 feet are 68 for the BOC regulation, but would decrease to 44, 30, and 29 in number, respectively, for Plans SO-901, SEO-42P, and Mods 7 and 8 of Plan SO-901. Although the absolute differences in the number of lake levels exceeding the index benchmarks of extreme levels are small for both Lake Superior and Lakes Michigan and Huron, it is important to recognize that relatively infrequent events can account for a very large portion of the total damages associated with an extended period of time.

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*Mr. Ben DeCooke of the U.S. Army Corps of Engineers, Detroit office, was asked in a personal communication to estimate the magnitudes of average monthly lake levels for Lakes Superior, Michigan and Huron above which complaints of damages to shore property became frequent. He estimated that a reasonable approximation would be about 601.4 feet for Lake Superior and 579.6 feet for Lakes Michigan and Huron. Although these levels represent a perception that is not based upon hard data, the University research team elected to utilize these levels as crude indices from which to judge relative hydrologic impacts of proposed management plans.

TABLE 26 LAKE SUPERIOR 1900-1973 — DIFFERENCES BETWEEN MONTHLY MEANS AND STANDARD DEVIATIONS FOR: BOC VERSUS SO-901, SEO-42P, SO-901 MOD 7, SO-901 MOD 8

	BOC		SO-901		[(SO-901) -(BOC)]		SEO-42P		[(SEO-42P) -(BOC)]	
	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
January	600.16	.55	600.21	.53	+.05	-.02	600.16	.56	--	+.01
February	599.96	.55	600.01	.56	+.05	+.01	599.97	.53	+.01	-.02
March	599.85	.55	599.90	.54	+.05	-.01	599.85	.56	--	+.01
April	599.94	.56	599.99	.56	+.05	--	599.95	.57	+.01	+.01
May	600.24	.60	600.28	.57	+.04	-.03	600.24	.59	--	-.01
June	600.54	.55	600.57	.59	+.03	+.04	600.53	.58	-.01	+.03
July	600.74	.53	600.77	.60	+.03	+.07	600.73	.59	-.01	+.06
August	600.84	.49	600.88	.59	+.04	+.10	600.84	.57	--	+.08
September	600.86	.55	600.90	.58	+.04	+.03	600.86	.57	--	+.02
October	600.79	.51	600.83	.56	+.04	+.05	600.79	.55	--	+.04
November	600.63	.52	600.68	.58	+.05	+.06	600.64	.56	+.01	+.04
December	600.40	.50	600.45	.55	+.05	+.05	600.41	.53	+.01	+.03
Year	600.41	.65	600.46	.67	+.05	+.02	600.41	.67	--	+.02

	SO-901 Mod 7		[(SO-901 Mod 7) -(BOC)]		SO-901 Mod 8		[(SO-901 Mod 8) -(BOC)]	
	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
January	599.74	.75	-.42	+.20	599.51	.78	-.65	+.23
February	599.55	.74	-.41	+.19	599.32	.79	-.64	+.24
March	599.44	.76	-.41	+.21	599.20	.83	-.65	+.28
April	599.53	.78	-.41	+.22	599.29	.82	-.65	+.26
May	599.82	.77	-.42	+.17	599.59	.81	-.65	+.21
June	600.11	.78	-.43	+.23	599.88	.82	-.66	+.27
July	600.31	.80	-.43	+.27	600.08	.84	-.66	+.31
August	600.42	.80	-.42	+.31	600.19	.85	-.65	+.36
September	600.44	.80	-.42	+.25	600.21	.84	-.65	+.29
October	600.37	.78	-.42	+.27	600.14	.82	-.65	+.31
November	600.22	.77	-.41	+.25	599.98	.80	-.65	+.28
December	599.99	.75	-.41	+.25	599.75	.79	-.65	+.29
Year	599.99	.86	-.42	+.21	599.76	.89	-.52	+.24

TABLE 27 LAKES MICHIGAN-HURON 1900-1973 — DIFFERENCES BETWEEN MONTHLY MEANS AND STANDARD DEVIATIONS FOR: BOC VERSUS SO-901, SEO-42P, SO-901 MOD 7, SO-901 MOD 8

	BOC		SO-901		[(SO-901) -(BOC)]		SEO-42P		[(SEO-42P) -(BOC)]	
	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
January	577.59	1.09	577.58	0.97	-.01	-.12	577.49	0.96	-.10	-.13
February	577.55	1.08	577.54	0.95	-.01	-.13	577.44	0.95	-.11	-.13
March	577.62	1.09	577.62	0.95	.00	-.14	577.52	0.95	-.10	-.14
April	577.88	1.11	577.87	0.98	-.01	-.13	577.77	0.97	-.11	-.14
May	578.19	1.13	578.19	1.02	.00	-.11	578.09	1.00	-.10	-.13
June	578.43	1.16	578.44	1.03	+.01	-.13	578.34	1.03	-.09	-.13
July	578.55	1.18	578.55	1.05	.00	-.13	578.46	1.04	-.09	-.14
August	578.50	1.19	578.50	1.06	.00	-.13	578.40	1.05	-.10	-.14
September	578.34	1.18	578.35	1.04	+.01	-.14	578.25	1.03	-.09	-.15
October	578.13	1.16	578.14	1.02	+.01	-.14	578.04	1.02	-.09	-.14
November	577.93	1.17	577.93	1.02	.00	-.15	577.83	1.02	-.10	-.15
December	577.75	1.13	577.75	1.02	.00	-.11	577.65	1.00	-.10	-.13
Year	578.04	1.19	578.04	1.07	.00	-.12	577.94	1.06	-.10	-.13

	SO-901 Mod 7		[(SO-901 Mod 7) -(BOC)]		SO-901 Mod 8		[(SO-901 Mod 8) -(BOC)]	
	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
January	577.59	0.87	.00	-.22	577.60	0.87	+.01	-.22
February	577.55	0.86	.00	-.22	577.56	0.86	+.01	-.22
March	577.63	0.88	+.01	-.21	577.63	0.86	+.01	-.23
April	577.88	0.90	.00	-.21	577.89	0.89	+.01	-.22
May	578.20	0.93	+.01	-.20	578.21	0.91	+.02	-.22
June	578.45	0.96	+.02	-.20	578.45	0.93	+.02	-.23
July	578.56	0.96	+.01	-.22	578.57	0.95	+.02	-.23
August	578.51	0.97	+.01	-.22	578.51	0.97	+.01	-.22
September	578.35	0.94	+.01	-.24	578.36	0.95	+.02	-.23
October	578.14	0.95	+.01	-.21	578.15	0.93	+.02	-.23
November	577.94	0.93	+.01	-.24	577.94	0.91	+.01	-.26
December	577.76	0.93	+.01	-.20	577.76	0.91	+.01	-.22
Year	578.05	0.99	+.01	-.20	578.05	0.98	+.01	-.21

TABLE 28 LAKE SUPERIOR — NUMBER OF MONTHLY MEAN LAKE LEVELS GREATER THAN 601.4 WITH SUPPLIES OF 1900-1973

		Greater than 601.4				
	Beginning-of-Month Recorded Data*	BOC	SO-901	SEO-42P	SO-901 Mod 7	SO-901 Mod 8
January	0	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	2	2	3	2	1	1
July	10	4	5	5	3	2
August	12	5	10	6	3	2
September	13	6	14	12	5	3
October	15	6	12	10	4	2
November	7	4	2	2	2	2
December	2	0	0	0	0	0
Total	61	27	46	37	18	12

TABLE 29 LAKES MICHIGAN-HURON — NUMBER OF MONTHLY MEAN LAKE LEVELS GREATER THAN 579.6 WITH SUPPLIES OF 1900-1973

		Greater than 579.6				
	Beginning-of-Month Recorded Data*	BOC	SO-901	SEO-42P	SO-901 Mod 7	SO-901 Mod 8
January	3	1	0	0	0	0
February	2	1	0	0	0	0
March	2	1	0	0	0	0
April	3	4	3	2	3	1
May	6	7	4	3	4	3
June	8	10	7	4	7	4
July	16	14	10	7	6	7
August	16	11	8	6	4	6
September	15	8	5	4	2	4
October	7	5	4	2	1	2
November	5	4	2	1	1	1
December	4	2	1	1	1	1
Total	87	68	44	30	29	29

Source: University of Wisconsin-Madison 1975.

Note: Based upon simulation of levels using Corps of Engineers computer program applied to IGLLB estimates of net basin supplies.

* Levels of IGLLB, Appendix B, Vol. 2, for months August-December (1900-1972 data).

The relative importance of isolated events, such as storms, to influence the rates of shoreline erosion has been illustrated by Brater (1975). Brater (1975, pp. 1-3) noted that while bluff erosion is greatest during periods of above normal lake levels, the most rapid shore erosion "occurs mainly during large storms which attack and erode the toes of bluffs." Because of the importance of storms to influence erosion, bluffs frequently continue to recede at modest rates even during periods of below average water levels.

However, the probability of storm generated waves being able to attack the base of a bluff is increased as mean water levels increase. The reader is reminded at this point of the concern expressed in section III of this report regarding the possibility that a large number of years represented in the data base utilized by the Levels Board were climatically biased towards conditions below long-term average net basin supplies. Tables 30 and 31 present data illustrating the apparent climatic influence on extreme lake levels of Lake Superior and Lakes Michigan and Huron for conditions of regulation under the BOC versus Plan SO-901. The three time intervals represented in Tables 30 and 31 are those identified in the climate study described in section III of this report. The data for Lake Superior in Table 30 indicate that nearly all of the instances in which the level 601.4 feet was exceeded occurred in the two relatively high net basin supply periods. The nonrandom distribution of "high" lake levels for Lake Superior is enhanced by the effects of Plan SO-901. For example, there were only four instances of exceeding 601.4 feet in the 30-year low supply period 1920-1949, but 49 such occurrences in the approximately 46 years characterized by relatively high net basin supplies. Given the concern expressed in section III, that high supplies of the past few years may indicate the trend for the next decade or two, it is significant that 33 of the 49 occurrences were associated with the period 1950-1975.

Table 31 presents a breakdown of the temporal distribution of occurrences of average monthly lake levels which would have exceeded 579.6 feet elevation according to regulation by the BOC and Plan SO-901 for net basin supplies of 1900-1975. Although the BOC data of Table 31 reveal that net basin supplies of the three periods 1900-1919, 1920-1949, and 1950-1975, produce a relative distribution of average monthly levels exceeding 579.6 feet elevation similar to the relative effects of supplies on Lake Superior "high" levels, the absolute differences are not as dramatic as shown for Lake Superior. Furthermore, the impact of Plan SO-901 is to reduce the relative differences in frequencies between the periods. On Lakes Michigan and Huron the number of occurrences of high levels associated with Plan SO-901 are less than the number of high levels associated with the BOC regulation in all three climatically designated intervals. A comparison of the Lakes Michigan and Huron data of Table 31 against the Lake Superior data of Table 30 reveals that the effects of regulation under Plan SO-901 increase the number of instances of high water levels, especially during periods of above average net basin supplies. Lakes Michigan and Huron in contrast, experience fewer occurrences of high water levels under the regulation of Plan SO-901. However, the effects of Plan SO-901 to increase the frequency of high water levels on Lake Superior appears to be grater than the effects of Plan SO-901 to reduce the frequency of high water levels on Lakes Michigan and Huron. This specific unfavorable impact on Lake Superior may, in part, account for the fact that

TABLE 30 1900-1975 — LAKE SUPERIOR

NUMBER OF AVERAGE MONTHLY LAKE LEVELS > 601.4 FEET ELEVATION

	1900-1919		1920-1949		1950-1975	
	BOC	SO-901	BOC	SO-901	BOC	SO-901
January	0	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	1	1	0	0	1	4
July	1	1	0	0	3	6
August	1	3	0	1	4	7
September	2	5	0	1	4	7
October	2	5	1	2	3	6
November	2	1	0	0	2	2
December	0	0	0	0	0	1
Year	9	16	1	4	17	33

TABLE 31 1900-1975 — LAKES MICHIGAN-HURON

NUMBER OF AVERAGE MONTHLY LAKE LEVELS > 579.6 FEET ELEVATION

	1900-1919		1920-1949		1950-1975	
	BOC	SO-901	BOC	SO-901	BOC	SO-901
January	0	0	0	0	3	4
February	0	0	0	0	4	4
March	0	0	0	0	4	4
April	1	0	2	1	5	4
May	2	2	2	1	7	4
June	7	5	2	2	7	7
July	9	7	3	3	9	10
August	8	5	3	3	10	10
September	3	2	2	1	9	8
October	1	0	1	1	8	5
November	0	0	1	1	5	4
December	0	0	1	0	4	4
Year	31	21	17	13	75	68

Source: University of Wisconsin-Madison 1975.

Note: The 1975 net basin supply data include only the first half of the year.

Lake Superior shore property can expect average annual net damages for lake level regulation by Plan SO-901 (Table 25). The unfavorable impact on Lake Superior may also partially explain why, under SO-901 regulation during periods of excessive net basin supplies to the Great Lakes as occurred 1968-1973, the estimated damages to shore property on Lake Superior apparently become so excessive that even the additional benefits accrued to shore interests on Lakes Michigan and Huron do not offset them (IGLLB 1973, Main Report, p. 235). Since the Plans SEO-42P and SEO-17P involve regulation of Lake Superior in the same general way as described for Plan SO-901, the relative impact of regulation on the number of occurrences of high water levels in climatically distinct periods would be similar to that described above for Plan SO-901. Hence, three of the five proposed regulation plans to control water level variations on the Great Lakes tend to increase the number of incidences of very high lake levels on Lake Superior. Although the three regulation plans would also decrease the number of occurrences of very high levels on Lakes Michigan and Huron, this reduction does not appear to be proportional to the relative increase expected for Lake Superior levels. Because the relative impact of regulation on increasing the incidence of high water levels on Lake Superior appears to be greatest during periods of above average net basin supplies, and because there is a reasonable chance that net basin supplies of the next one or two decades may exceed the average of the IGLLB base period 1900-1967, special compensation to shore property interests should be considered for Lake Superior.

Regulation of water levels according to rules of the five proposed regulation plans described above also affects the number of times that average monthly lake levels drop below the mean low water datum of each of the lakes. However, it is apparent from the data of Tables 32 and 33 that only Mods 7 and 8 of Plan SO-901 produce significant adjustments in the frequencies of average monthly levels which are less than low water datum elevations. For example, the data of Tables 32 and 33 indicate that the number of occurrences of "low" water levels on Lakes Superior, Michigan and Huron for Plan SO-901 and SEO-42P differ little from the number of occurrences of low water levels expected for regulation by the BOC for supplies of 1900-1973. However, regulation of the two lake systems according to Mods 7 and 8 of Plan SO-901 increases the number of low water occurrences on Lake Superior from 214 for the BOC to 445 for Mod 7 and 516 for Mod 8; on Lakes Michigan and Huron the impact is in the opposite direction as the number of low water occurrences decreases from 131 for the BOC to 87 for Mod 7 and 82 for Mod 8. The high number of occurrences of low water on Lake Superior represents the principal negative aspect of the Mod plans. Because the high frequency of low water levels would represent a great hindrance to navigation interests, dredging would be required to deepen Lake Superior harbors and channels and parts of the St. Marys River.

5. Temporal Patterns in "SO" Regulation Effects

The "SO" regulation concept, as represented in Plan SO-901, involves manipulation of flows in the St. Marys River in such a way as to keep the levels of Lake Superior and Lakes Michigan and Huron at relatively the same position with respect to their mean levels (e.g., the same number of standard deviations from their respective means) (IGLLB 1973, Main Report, p. 109). In theory "SO" regulation would seem to reduce the extreme levels on both lake systems because the lake which would be in a less extreme situation would be used to

TABLE 32 LOW WATER DATUM - LAKE SUPERIOR
NUMBER OF MONTHLY MEAN LAKE LEVELS LESS THAN 600.0
WITH SUPPLIES OF 1900-1973

	Beginning-of-Month Recorded Data*	BOC	SO-901	SEO-42P	SO-901 Mod 7	SO-901 Mod 8
January	11	23	27	29	45	52
February	23	43	38	40	53	60
March	35	48	45	46	57	60
April	40	45	39	40	50	60
May	26	19	21	22	43	48
June	7	7	11	12	32	38
July	6	5	5	6	26	33
August	3	4	2	4	24	29
September	2	4	0	1	24	28
October	2	4	1	2	25	32
November	3	4	5	5	31	35
December	5	8	14	16	35	41
Total	163	214	208	223	445	516

TABLE 33 LOW WATER DATUM - LAKES MICHIGAN-HURON
NUMBER OF MONTHLY MEAN LAKE LEVELS LESS THAN 576.8
WITH SUPPLIES OF 1900-1973

	Beginning-of-Month Recorded Data*	BOC	SO-901	SEO-42P	SO-901 Mod 7	SO-901 Mod 8
January	15	15	14	15	14	13
February	16	15	14	18	12	13
March	16	13	12	14	12	12
April	13	11	12	12	11	9
May	12	10	5	7	4	3
June	7	7	4	5	2	1
July	4	5	4	5	1	1
August	3	6	5	5	1	1
September	10	9	4	7	3	3
October	10	12	9	11	5	4
November	12	14	13	14	10	10
December	14	14	13	16	12	12
Total	132	131	109	129	87	82

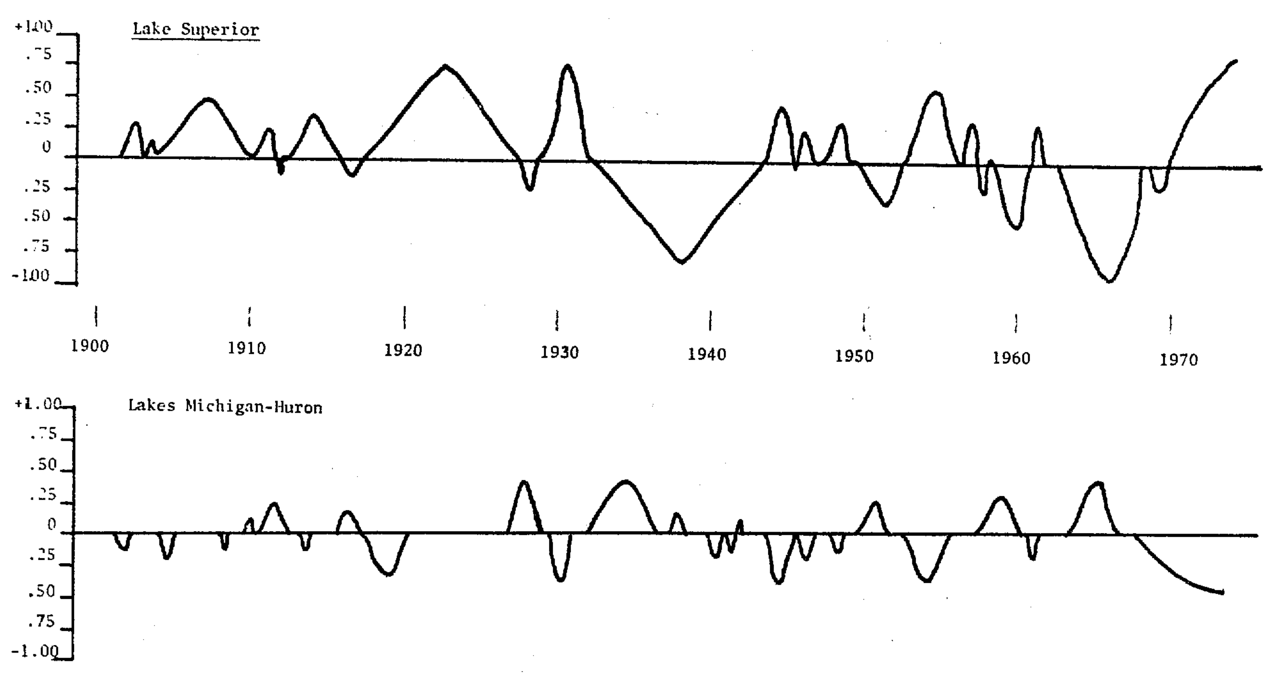
Source: University of Wisconsin-Madison 1975.

* Low Water Datum - Navigation season extends from April 1 - November 30.

relieve conditions on the other (IGLLB 1973, Main Report, p. 109). In fact, however, the effectiveness of the "SO" plans to control lake level extremes depends in part on the pattern of occurrence of net basin supplies. Preliminary analyses by the University group suggest that "SO" regulation is more effective if occurrences of either above average or below average net basin supplies do not occur in clustered sequences. The reader may recall, however, that climatic investigations described in section III of this hydrology report clearly indicate that clustering is a prevalent situation. The effects of "SO" regulation on clustered sequences of net basin supplies often result in the persistence of relatively unfavorable lake level conditions on Lake Superior relative to Lakes Michigan and Huron, as is indicated in Figure 59.

If climatic effects on net basin supplies were truly random in character, then the "balancing" concept of the "SO" regulation plans should result in a somewhat random pattern in the differences between levels for "SO" regulation versus expected levels for BOC regulation. The plot of differences of levels for Lake Superior on Figure 59 suggests that differences tend to persist over a few years either above or below the zero line and that "SO" regulation has frequently resulted in Lake Superior being higher than it would have been were BOC regulation practiced. The Lake Superior plot of differences also reveals that the two periods during which SO-901 regulation would have produced lower levels than BOC regulation (late 1930s and the middle 1960s) were actually periods of low net basin supplies. Hence, it would have been advantageous to Lake Superior interests to have maintained higher levels during those two periods.

FIGURE 59 GENERALIZATION OF LAKE LEVEL DIFFERENCES BETWEEN PLAN SO-901 AND BOC (SO-901 - BOC IN FEET)



Source: University of Wisconsin-Madison 1975.

Note: Based on simulation of levels using Corps of Engineers computer programs applied to IGLLB estimates of net basin supplies 1900-1973.

The long-term pattern of differences of average monthly levels for SO-901 versus BOC on Lakes Michigan and Huron indicate that SO-901 has quite favorable effects (Figure 59). The differences of levels between the two regulation plans are relatively conservative compared to differences of levels for Lake Superior. Furthermore, an inspection of the temporal distribution of differences indicated that SO-901 slightly reduced average monthly levels below those expected for BOC regulation during periods of excessive supplies and that SO-901 slightly increased average monthly levels above those expected for BOC regulation during periods of below average supplies.

In summary, the graphs of Figure 59 suggest that "SO" regulation may be expected to produce negative impacts to Lake Superior interests most of the time, including certain periods of below average net basin supplies. In contrast, Lakes Michigan and Huron may generally expect to receive favorable impacts on lake levels from "SO" regulation schemes.

The reduced effectiveness of the SO-901 regulation of lake levels as related to persistence of large departures from average net basin supplies would also occur with Plans SEO-42P and SEO-17P because the two SEO plans utilize the same Lake Superior discharge rule as in Plan SO-901. Mods 7 and 8 of Plan SO-901 are also affected by persistence of deviations of net basin supplies, but the effects are somewhat different than described for SO-901.

The impact of persistent departures of supplies on the effectiveness of the Mod plans to regulate lake levels is somewhat different than the effects described above for the other "SO" or "SEO" plans because the Mod plans incorporate a greater range of tolerable lake levels for Lake Superior. However, regulation according to rules of the Mod plans also appears to produce many negative impacts to Lake Superior. For example, a plot of the time series of August mean lake levels for Lake Superior reveals that maximum levels during episodes of excessive net basin supplies as occurred about 1916, 1928-1929, and 1951-1952 would have produced high levels under Mod 8 regulation that were not greatly different from levels which would have occurred with BOC regulation (Figure 60). Furthermore, during periods of very low net basin supplies in the middle 1920s and the 1930s, when more water would have been released to increase the levels of Lakes Michigan and Huron, the levels on Lake Superior for Mod 8 regulation would have fallen far below levels of the same period expected for BOC regulation. It is clear that dredging of Lake Superior channels and harbors would be necessary to prevent major negative impacts to navigation interests during such periods of low net basin supplies. Figure 61 compares the average monthly levels on Lake Superior and Lakes Michigan and Huron for various regulation plans representing the period 1961-1973. A comparison of levels associated with Mod 7 of SO-901 versus levels associated with other regulation plans, including the BOC, indicates that Mod 7 regulation generally is beneficial to lake level related interests on Lakes Michigan and Huron.

In summary, the five regulation plans currently being considered for possible adoption, which include Plan SO-901, Mods 7 and 8 of Plan SO-901, SEO-42P, and SEO-17P, all appear to impose significant negative impacts on Lake Superior average monthly levels relative to levels expected for BOC regulation. In contrast, the five regulation plans almost always produce favorable impacts to lake levels on Lakes Michigan and Huron when compared to levels associated with the BOC. This relative discrepancy indicates the importance of Lake Superior to function as a reservoir to regulate lake levels on the lower Great Lakes.

FIGURE 60 THE EFFECTS OF REGULATION ON AUGUST AVERAGE LAKE LEVELS (1911-1960)

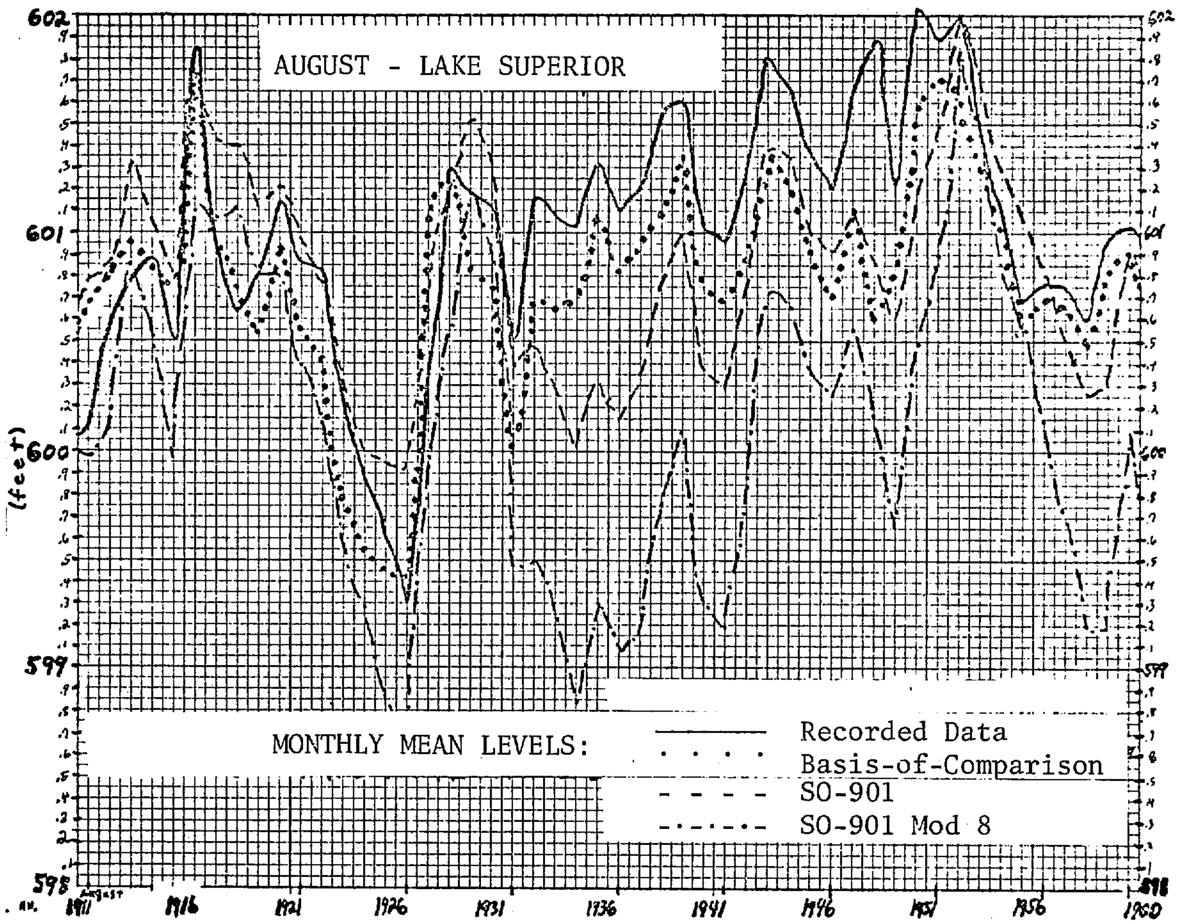
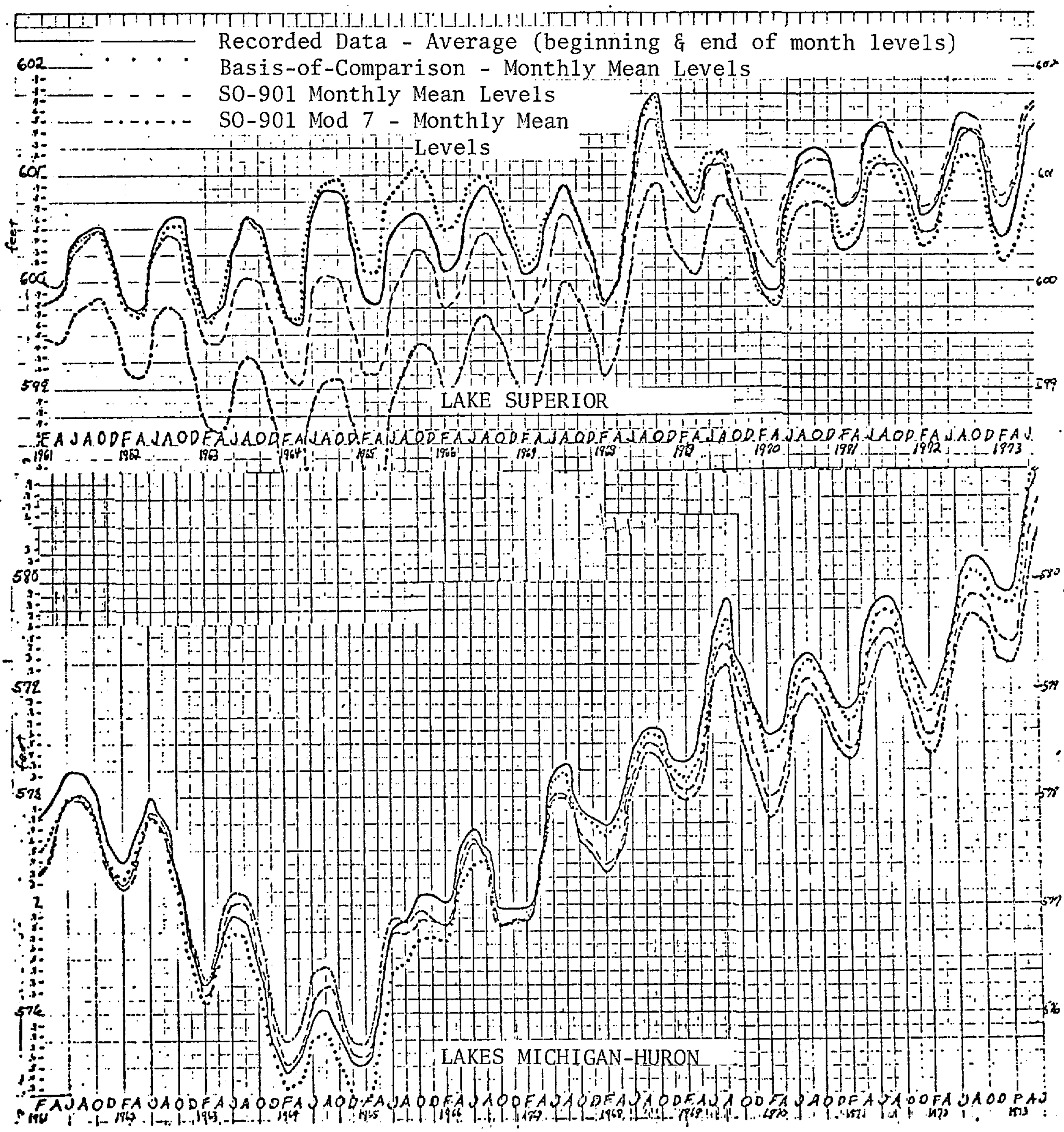


FIGURE 61 THE EFFECTS OF REGULATION ON AVERAGE MONTHLY LAKE LEVELS ON LAKE SUPERIOR AND LAKES MICHIGAN AND HURON (1961-1973)



C. Summary

In the Upper Great Lakes Region, concern is focussed on five proposed regulation plans which include: Plan SO-901, Mods 7 and 8 of Plan SO-901, Plan SEO-42P, and Plan SEO-17P. All five plans incorporate a regulation rule which involves the manipulation of flows in the St. Marys River in such a way as to keep the levels of Lake Superior and Lakes Michigan and Huron at relatively the same position with respect to their long-term mean levels. The objective of the rule is to reduce the extreme levels on both Lakes Superior, Michigan and Huron using the lake which would be in a less extreme situation to relieve conditions on extreme levels on the other lake. The results of the University research revealed that the management plans proposed by the IGLLB preserved, in general, the normal pattern of seasonal variations of lake levels.

Plan SO-901 has the general tendency to cause Lake Superior to be somewhat higher than it normally would be relative to the Basis-of-Comparison (BOC) regulation scheme. Plan SO-901 also has the general tendency to cause Lakes Michigan and Huron to be slightly above BOC levels during periods of below normal net basin supplies and slightly below expected BOC levels during periods of above normal net basin supplies.

Mods 7 and 8 of Plan SO-901 incorporate the same between lake balancing concept as described for SO-901, but involve lowering the mean level of Lake Superior by 0.5 to 9.8 feet below the mean levels associated with Plan SO-901. At the same time, the standard deviation of Lake Superior levels about the mean is increased by approximately 30%. The Mod plans generally preserve the mean level of Lakes Michigan and Huron relative to Plan SO-901, but they only slightly reduce the variance of levels about the mean.

The SEO plans involve regulation of Lake Superior discharges according to the general guidelines defined for Plan SO-901. The principal difference between the SEO plans and SO-901 is that the SEO plans call for an enlargement of the outlet capacity of Lake Erie to permit the passage of additional discharge during periods of excessive net basin supplies. The additional discharge amounts to approximately 8,000 cfs for SEO-42P and approximately 17,000 cfs for SEO-17P. Because Lake Superior is regulated relatively similarly under both SEO and SO-901 plans, little difference is apparent in the characteristics of lake levels between the two regulation schemes. However, the long-term mean level of Lakes Michigan and Huron would be reduced by approximately 0.1 feet by the SEO plans relative to Plan SO-901, and the long-term mean level of Lake Erie would be approximately 0.3 feet lower under the SEO plans compared to the long-term mean level for Plan SO-901.

It is concluded that the proposed lake level management plans have relatively modest effects on the long-term mean levels of the Great Lakes. All five of the proposed lake level regulation plans have the potential to exert great impacts on lake levels, but this potential is never achieved because full-scale implementation of the plans would result in major negative impacts to certain interest groups, e.g., shore property, navigation, and power.

For example, University analyses of 1900-1973 net basin supplies revealed that Plan SO-901 would have been constrained by rule limitations affecting maximum or minimum outflow capacities about 59% of the time. Comparable figures for Mods 7 and 8 of Plan SO-901 are 57% and 54% respectively. Although no comparable analyses were conducted for the SEO plans, it is expected that rule constraints would affect them in a similar way because the SEO plans incorporate the same Lake Superior discharge rule as for Plan SO-901.

The impact of the five proposed lake level regulation plans to affect the number of occurrences of extremely high and extremely low water levels is also modest, but the effect is significant because extreme damages are frequently associated with such extreme levels. Three of the regulation plans, SO-901, SEO-42P, and SEO-17P, appear to significantly increase the frequency of extreme high levels on Lake Superior while at the same time produce a modest reduction in the extreme high levels for Lakes Michigan and Huron. Mods 7 and 8 of Plan SO-901 apparently reduce the frequency of extreme high levels on both Lake Superior and Lakes Michigan and Huron, but these benefits appear to be offset by an associated major increase in the frequency of extreme low levels on Lake Superior. Consequently, the Mod plans would require expensive dredging of Lake Superior harbors and channels as well as in selected locations of the St. Marys River.

Interpretation of the impact of lake level regulation on the occurrence of lake level extremes is somewhat confused by the possibility that the climatic characteristics of the years represented in the data base may not accurately represent net basin supply characteristics of the next one or two decades or longer. Studies of long-term climate variations suggest there is a reasonable chance that the Upper Great Lakes Region may be heading into a period characterized by higher magnitudes of net basin supplies than those magnitudes which dominated the first half of the twentieth century. The University study of when extreme high levels occur indicated that lake level regulation according to Plan SO-901 or by the two SEO plans would very significantly increase the number of extreme high levels on Lake Superior if high supply conditions were to become more frequent.

In conclusion, Mods 7 and 8 of Plan SO-901 appear to represent the most effective regulation of lake levels relative to the five plans discussed in this report. Unfortunately, the benefits of the Mod plans are reduced by costs of dredging to prevent serious impediments to navigation interests. The Mod plans also greatly increase the range of water levels on Lake Superior and may therefore impose negative impacts on wetland resources. Of the several proposed management plans, Plan SO-901 appears to provide the most benefits for the least investment. It is very possible that significant improvements to Plan SO-901 could be achieved by implementing a greater range of variability in Lake Superior discharges through the St. Marys River. It is also possible that additional benefits with Plan SO-901, as well as with other plans, could be achieved by tolerating a greater range of variation in the various diversions which feed in and out of the Great Lakes. The impacts of diversions are discussed in the following section of this report.

V. DIVERSIONS

Water is being diverted into the Lake Superior Basin from Long Lake and the Ogoki River in Ontario, Canada, and out of the Lake Michigan Basin in the Greater Chicago area of Illinois. The magnitudes of the diversions generally have been determined by the particular agencies directly concerned with the diverted water, with little consideration given to their effect on the levels of the Great Lakes.

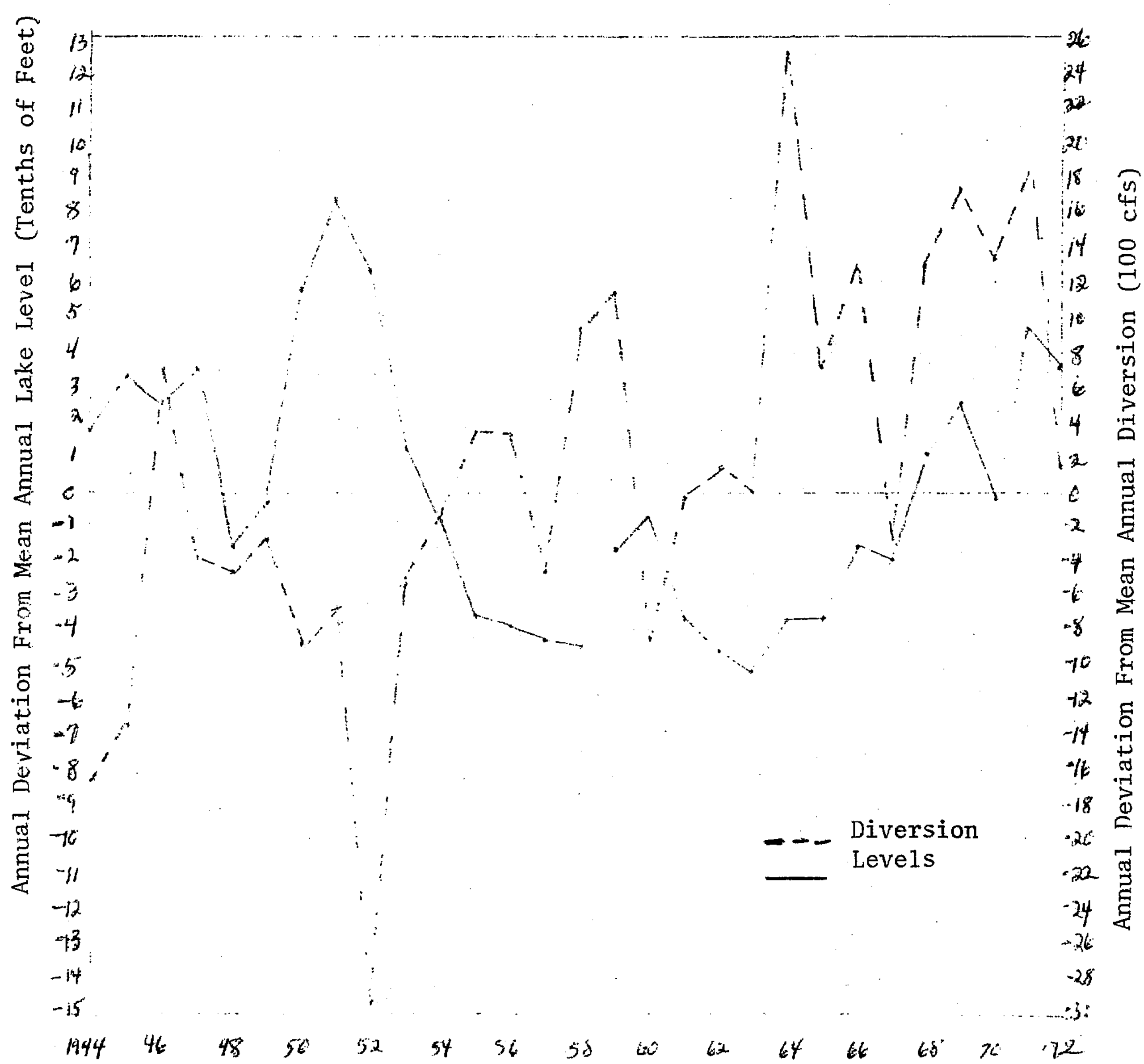
The Long Lake diversion connects the headwaters of the Kenogami River, which originally flowed through the Albany River Basin, with Long Lake. Long Lake flows into the Aguasabon River, which discharges directly into Lake Superior. The diversion began in 1939 and has averaged 1,450 cfs. A hydroelectric power plant uses the increased flow of the Aguasabon River.

The Ogoki River diversion connects part of the Ogoki River, which originally flowed through the Albany River Basin, with the Little Jackfish River. The Little Jackfish River flows into Lake Nipigon, and thence through the Nipigon River into Lake Superior, about 95 miles west of the mouth of the Aguasabon River. This diversion began in 1943 and has averaged 4,000 cfs. There are three hydroelectric power plants on the Nipigon River. Lake Nipigon is regulated by a rule curve designed to maintain maximum dependable flow down the Nipigon River for power interests. In order to maintain dependable flow in the Nipigon River the rule curve usually requires that the entire Ogaki watershed be passed into Lake Nipigon. Partial closure of the diversion occurs when the elevation of Lake Nipigon reaches 854 feet and full closure at 854.5 feet. The diversion has been reduced or closed approximately twenty times since 1943 as called for by the Lake Nipigon rule curve (Great Lakes Basin Framework Study 1975, Appendix 11, p. 47). It has also been closed (from 1951-1953 and 1973) at the request of the United States government in consideration of high lake levels.

The magnitude of the diversion from Lake Michigan in the Greater Chicago area is limited by a 1967 Supreme Court decree to an average annual rate of 3,200 cfs, accounted for every five years, with an average for any one year not to exceed 3,520 cfs. The diversion has served four main purposes: to dilute the effluent of the Chicago sanitary district; to allow for navigation in the Sanitary and Ship Canal; to provide for public water supply; and to increase power generation at Lockport and Marseilles, Illinois. Approximately 1,700 cfs is used for public water supply, 1,000 cfs is diverted directly from the lake for navigation and sanitary purposes, and 500 cfs is indirectly diverted as surface runoff and groundwater baseflow (Northeastern Illinois Planning Commission Report 1974, p.3).

In consideration of the agencies using the diverted water it can be inferred that the magnitudes of the diversions into and out of Lakes Superior and Michigan have not been operated in a manner designed to reduce the variance in the levels of the Great Lakes. In Figure 62, the Long Lake-Ogoki annual deviation from its 1944-1972 mean is compared to the deviation in Lake Superior levels during this period. The figure shows that slightly more water has been diverted into Lake Superior when the levels were low, and slightly

FIGURE 62 LONG LAKE-OGOKI DEVIATION FROM THE MEAN ANNUAL DIVERSION AND DEVIATION OF LAKE SUPERIOR MEAN ANNUAL LEVELS FROM THE LONG-TERM MEAN LEVEL (1944-1972)



less water has been diverted when the levels were high. In interpreting Figure 62 it should be understood that the amount of water diverted from the Ogoki watershed does not immediately flow into Lake Superior, but is held on Lake Nipigon and released according to the Lake Nipigon rule curve.

Studies have estimated the ultimate effect on the upper lakes of permanently increasing the rate of diversion from Lake Michigan at Chicago. The ultimate effect takes several years to occur (shown on Table 34). During this time, the levels may change from one extreme to the other. Conditions would then call for a change in the rate of diversion. For this reason it may be desirable to have a plan controlling diversions which considers the levels of the lakes themselves, as well as the needs of the entities directly concerned with the diverted water.

Such a plan may involve variable diversions at Chicago and Long Lake-Ogoki by requiring individual release rules for each diversion. The rules can then be incorporated in the Basis-of-Comparison model of the IGLLB to test the effect of the variable diversion plan on the 67-year record of lake levels and outflows.

The simplest release procedure that can be used is a linear decision rule based on the mean monthly level of the lake where the diversion enters or leaves. The rule developed here incorporates the minimum and maximum Z-scores $\left(\frac{L-\overline{L}}{\sigma L}\right)$ for levels on a particular lake and the average, minimum and maximum diversions into or out of that lake over the historical record. Where L is the mean monthly lake level, σL equals the standard deviation of mean monthly lake level (1900-1967), and $\overline{L}$ is the average mean monthly lake level (1900-1967).

The release rule for the Long Lake-Ogoki diversion is as follows:

$$R = D\ Max. \qquad \text{for } Z \leq Z\ Min.$$

$$R = \overline{D} = \left(\frac{D\ Max.-\overline{D}}{Z\ Min.}\right)Z \qquad \text{for } Z\ Min. \leq Z \leq 0$$

$$R = D\ Min. = \left(\frac{\overline{D} - D\ Min.}{Z\ Max.}\right)Z \qquad \text{for } 0 \leq Z \leq Z\ Max.$$

$$R = D\ Min. \qquad \text{for } Z > Z\ Max.$$

where:

R = average monthly release
$\overline{D}$ = average diversion over the historical record
D Min. = minimum diversion over the historical record
D Max. = maximum diversion over the historical record
Z Min. = minimum Z-score over the historical record for Lake Superior
Z Max. = maximum Z-score over the historical record for Lake Superior

TABLE 34 THE EFFECTS ON THE LEVELS OF LAKES MICHIGAN AND HURON OF INCREASING THE CHICAGO DIVERSION TO A PERMANENT MAGNITUDE OF 10,000 CFS

Year	Lowering Effect of 10,000 cfs (in)	Lowering Effect of 3,200 cfs (in)	Difference
1	2.42	.7435	1.68
2	4.25	1.3054	2.94
3	5.57	1.7103	3.86
4	6.52	1.9990	4.53
5	7.22	2.2142	5.00
6	7.70	2.3629	5.34
7	8.08	2.4785	5.60
8	8.35	2.5610	5.79
9	8.56	2.6270	5.93
10	8.70	2.6680	6.03
11	8.81	2.7010	6.11
12	8.89	2.7260	6.16
13	8.95	2.7420	6.21
14	8.97	2.7500	6.22
15*	8.99	2.7550	6.23

Source: Louis D. Kirshner 1968.

* Year 15 represents the ultimate effect. The values when converted to feet are .75, .23, and .52, respectively. The term "Ultimate Effects" implies that a certain interval of time must elapse before the full effect of a diversion takes place. For example, it takes approximately 15 years for the diversion at Chicago to have an ultimate effect on Lake Michigan. This point is reached when the rate of outflow from Lakes Michigan and Huron is no longer decreased by the effect of the diversion. The values listed above are based on the assumptions that each lake, at the beginning of the month, is at its mean level and the net total supply of water being received by each lake is equal to its outflow.

To account for monthly and seasonal variations in lake levels and diversions in the past, the historical data are divided into 12 monthly groupings. Thus, there is a different release rule for each month and there are 48 equations to be incorporated into the Basis-of-Comparison model for each diversion. The data used to develop this release rule for the Long Lake-Ogoki diversion is summarized in Table 35. The release rule for January is given below as an example:

$$
\begin{array}{ll}
R = 7.5 & \text{for } Z \leq -0.71 \\
R = 4.8 - 3.8Z & \text{for } -0.71 \leq Z \leq 0 \\
R = 2.9 + .96Z & \text{for } 0 \leq Z \leq 1.98 \\
R = 2.9 & \text{for } Z \geq 1.98
\end{array}
$$

Under this rule, when the lake is at its mean level ($Z = 0$) the average diversion (over the historical record) is allowed to be released. As the lake level falls below its mean level, the diversion is allowed to increase linearly until the maximum allowable release is reached. The diversion remains at this level no matter how much the lake level decreases. This constraint is based upon the historical channel capacity of the diversion. As the lake level rises above its mean level, the diversion is allowed to decrease linearly until the minimum allowable release is reached.

The release rule for the Chicago diversion is similar except that water is now being diverted from a lake and not into it. Thus, when levels are high, release into the canal should be high and vice versa. The equations are basically the same as before but the boundary conditions change. The release rule for the Chicago diversion is as follows:

$$
\begin{array}{ll}
R = D\text{ Min.} & \text{for } Z < Z\text{ Min.} \\
R = D\text{ Min.} + \left(\dfrac{\overline{D} - D\text{ Min.}}{Z\text{ Min.}}\right) Z & \text{for } Z\text{ Min.} \leq Z \leq 0 \\
R = \overline{D} + \left(\dfrac{D\text{ Max.} - \overline{D}}{Z\text{ Max.}}\right) Z & \text{for } 0 \leq Z \leq Z\text{ Max.} \\
R = D\text{ Max.} & \text{for } Z > Z
\end{array}
$$

where:

Z Min. = minimum Z-score over the historical record for Lake Michigan
Z Max. = maximum Z-score over the historical record for Lake Michigan

Once again, when the lake is at its mean level, the average diversion is released. As the lake level falls below its mean level, the diversion is allowed to decrease linearly until the minimum allowable release is reached. As the lake level rises above its mean level, the diversion is increased linearly until the maximum allowable release is reached. The data used to develop the release rules for the Chicago diversion is also summarized in Table 35.

TABLE 35 MONTHLY DIVERSIONS INTO LAKE SUPERIOR OUT OF LAKE MICHIGAN (1944-1973)

Month	Average Diversion	Maximum Diversion	Maximum Z (Level-Lake Superior)	Minimum Diversion	Minimum Z (Level-Lake Superior)
January	4.80	7.5	1.98	2.9	-0.71
February	4.07	5.9	1.83	2.1	-0.61
March	3.49	4.9	1.66	1.9	-0.69
April	3.47	4.9	1.79	1.9	-0.63
May	7.23	11.2	1.83	1.0	-9.90
June	10.02	17.7	1.82	2.1	-1.12
July	7.35	12.8	1.78	1.3	-0.95
August	5.83	12.1	1.77	1.2	-0.80
September	5.19	12.3	1.79	1.3	-0.75
October	5.38	12.7	2.02	1.2	-0.78
November	5.65	12.6	1.95	0.9	-0.69
December	5.44	10.4	2.02	2.6	-0.74

CHICAGO DIVERSION
(1900-1972)

Month	Average Diversion	Maximum Diversion	Maximum Z (Level-Lakes Mich.-Huron)	Minimum Diversion	Minimum Z (Level-Lakes Mich.-Huron)
January	5.09	10.1	1.71	2.0	-2.28
February	5.06	10.2	1.82	2.0	-2.27
March	5.13	10.0	1.44	1.8	-2.30
April	5.36	10.3	1.82	2.1	-2.34
May	5.42	10.1	2.05	2.6	-2.34
June	5.70	10.3	2.17	2.6	-2.39
July	5.71	10.2	2.07	2.9	-2.34
August	5.94	10.4	1.98	2.9	-2.27
September	5.64	11.0	1.92	2.9	-2.26
October	5.40	11.4	1.76	2.3	-2.26
November	5.29	11.1	1.78	2.0	-2.32
December	5.43	10.3	1.88	2.2	-2.29

Note: Diversion values are in 1,000 cfs.

Several political and physical constraints concerning the magnitudes of the diversions must be considered in the development of a variable diversion plan that is dependent on the levels of the lakes. The Canadian government has consistently opposed any increase in the Chicago diversion. It has stated that such an increase would constitute an irritant to good relations between Canada and the United States because of the effect it would have on Canada's navigation and power interests. The states of Wisconsin, Minnesota, Ohio, Pennsylvania, Michigan, and New York have also opposed an increase at Chicago in the past; this led to the 1967 decree. The United States government has asked the Canadian government to curtail the Long Lake and Ogoki diversions in times of high lake levels. The Canadian government has complied only to the extent that the reduced flows do not greatly interfere with its power interest, and the Canadians claim that the exchange of notes in 1940 and 1941 justify an average release of 5,000 cfs (RF Monograph 76-05-Institutions).

The proposed variable diversion plan has incorporated, to a limited extent, the physical constraints imposed on the magnitudes of diversions over the period of operation. Since the maximums, minimums, and averages for each month over the period of operation are used in the determination of the amount to be released, inherent constraints have been built into the plan which reflect the constraints of the past. However, conditions at present are not identical to those which have existed in the past. For this reason, the proposed plan should be modified to accommodate more recent limitations. Some of the limitations which should be considered in determining the amount of water actually diverted include:

- A maximum outflow from Lake Nipigon to prevent excessive scouring and damage to rail and highway crossings

- A minimum outflow from Long Lake which would not severely impair the communities dependent on this flow for power.

- A minimum outflow through the Chicago diversion; enough to meet essential needs, i.e., public water supply, etc.

- High water conditions on the Illinois River and the Mississippi must not be augmented. Drainage and levee districts on the Illinois River have adamantly opposed an increase in the amount of water diverted from Lake Michigan in expectation that it would subject more pressure to levees and seawalls, increase pumping costs for agriculture, increase erosion of the river banks, and endanger communities whose flood control measures were designed for a lower rate of diversion. Table 36, showing the flow characteristics of the Chicago Sanitary and Ship Canal, the Illinois River at Marseilles, and the Mississippi River near Chester, Illinois, for the water year of October 1973 to September 1974, has been included to indicate the relative degree to which the Illinois and Mississippi rivers are affected by the Lake Michigan diversion.

TABLE 36 FLOW CHARACTERISTICS OF THE CHICAGO SANITARY AND SHIP CANAL, THE ILLINOIS RIVER AT MARSEILLES, ILLINOIS, AND THE MISSISSIPPI RIVER NEAR CHESTER, ILLINOIS

ILLINOIS RIVER BASIN

	TOTAL DISCHARGE			Mean Direct Diversion And Storm Runoff	Domestic Pumpage Mean	TOTAL DIVERSION		
Month	Maximum Daily	Minimum Daily	Mean			Maximum Daily	Minimum Daily	Mean
OCT	9,504	1,589	2,644	689	1,678	8,969	1,391	2,367
NOV	3,078	1,564	2,096	312	1,553	2,718	1,388	1,865
DEC	7,863	1,609	3,069	1,178	1,517	7.403	1,365	2,695
1973	16,424	1,060	3,392	1,334	1,691	14,543	723	3,025
JAN	9,779	1,774	3,479	1,335	1,567	8,907	1,228	2,902
FEB	11,680	1,872	3,207	1,236	1,546	10,443	1,630	2,782
MAR	6,157	1,914	3,117	1,114	1,539	5,587	1,626	2,653
APR	12,120	1,531	3.779	1,763	1,562	11,423	1,111	3,325
MAY	24,810	2,125	6,028	3,815	1,594	23,465	1,871	5,409
JUN	17,136	2,355	4,471	2,368	1,743	16,293	1,950	4,111
JUL	10,019	1,988	2,982	648	2,114	9,601	1,792	2,762
AUG	4,246	1,841	2,472	290	1,958	4,032	1,561	2,248
SEP	4,677	1,624	2,171	209	1,773	4,447	1,458	1,982
Water Year 1973-74	24,810	1,531	3,293	1,246	1,679	23,465	1,111	2,925

Source: Wisconsin v. Illinois 388 U.S. 426 (1968) Report of Albert B. Maris.

	Illinois River at Marseilles			Mississippi River at Chester		
Month	Maximum	Minimum	Mean	Maximum	Minimum	Mean
OCT	12,800	3,330	5,210	438,000	246,000	357,000
NOV	5,750	3,420	4,288	347,000	176,000	231,000
DEC	19,400	4,310	8,865	423,000	149,000	270,000
JAN	46,700	5,200	18,190	509,000	142,000	279,000
FEB	39,800	8,850	17,840	498,000	232,000	331,000
MAR	26,600	9,980	18,080	478,000	271,000	354,000
APR	31,400	9,230	16,670	335,000	265,000	310,000
MAY	60,400	8,200	25,340	534,000	248,000	337,000
JUN	34,600	7,270	17,530	530,000	371,000	458,000
JUL	10,300	3,800	5,758	411,000	141,000	244,000
AUG	6,510	3,230	4,560	159,000	120,000	136,000
SEP	7,920	3,070	4,355	157,000	82,000	122,000

APPENDIX

THE COMPUTER PROGRAM COMPARING VARIOUS REGULATION PLANS

The Water Resources Management (WRM) Workshop compared the mean monthly lake levels for various regulation plans (SO-901, SO-901 Mod 7, SO-901 Mod 8, SEO-42P and Basis-of-Comparison) by using lake level data generated by IGLLB computer simulation programs. The Corps of Engineers computer program was modified to compare, by month, simulated mean monthly levels on any lake for a designated pair of regulation plans. This program provides three major types of information:

- Statistical data on each of the two regulation plans being compared
- Magnitude and frequency of differences between lake levels of the two plans
- Mean monthly lake levels of each of the two plans from 1900 through 1973.

STATISTICAL DATA

The computer program lists, by month, the following statistical parameters measured over the historical record from 1900 through 1973 for each of the two plans: mean lake level (feet above International Great Lakes Datum 1955) variance and standard deviation (feet), and minimum and maximum mean monthly levels (feet). In addition, the program lists, using 0.2-foot intervals, the distribution of simulated monthly levels during the 74-year period. Table 37 is an example of these calculations for Lake Superior mean levels for January comparing Plan SO-901 and BOC.

TABLE 37 SO-901 VS BOC SUPERIOR MEANS (JANUARY 1900-1973)

FEET	598		599					600					601					602			OVER	
TENTHS	U.6	.8	.0	.2	.4	.6	.8	.0	.2	.4	.6	.8	.0	.2	.4	.6	.8	.0	.2	.4	.4	SO-901
NUMBER MONT	0	0	0	1	2	4	8	12	8	13	10	8	7	0	1	0	0	0	0	0	0	

MEAN 600.21 VARIANCE .28 STANDARD DEV .53 MIN 599.11 MAX 601.36

FEET	598		599					600					601					602			OVER	
TENTHS	U.6	.8	.0	.2	.4	.6	.8	.0	.2	.4	.6	.8	.0	.2	.4	.6	.8	.0	.2	.4	.4	BOC
NUMBER MONT	0	1	1	0	1	2	3	15	20	12	10	2	4	2	1	0	0	0	0	0	0	

MEAN 600.16 VARIANCE .30 STANDARD DEV .55 MIN 598.66 MAX 601.36

Source: University of Wisconsin-Madison 1975.

MAGNITUDE AND FREQUENCY OF DIFFERENCE

Table 38 is an example matrix of the differences between Plan SO-901 and BOC. It indicates for a particular month the number of times that the mean monthly level of one plan is higher or lower than that level of the other plan. The level of one plan is listed in 0.2-foot intervals, and the difference between the plan and the compared plan is listed in 0.1-foot intervals. For example, Table 38 compares Plan SO-901 vs. BOC for January mean monthly levels on Lake Superior from 1900-1973. The circled number in the matrix indicates that during one year the January level of SO-901 was one foot lower than BOC when the SO-901 level was between 599.2 and 599.4 feet. The main purpose of such a matrix is to indicate whether one plan tends to be higher or lower than another plan for any particular month, and if so, at what levels these differences occur.

TABLE 38 SO-901 VS BOC (JANUARY 1900-1973)

FREQUENCY (NO. OF MONTHS) DIFFERENCES IN LEVELS CASE 1 HIGHER OR LOWER

FEET		598		599					600					601					602			OVER
TENTHS		U.6	.8	.0	.2	.4	.6	.8	.0	.2	.4	.6	.8	.0	.2	.4	.6	.8	.0	.2	.4	.4
OVER		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H	.8	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
I	.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	.6	0	0	0	0	0	1	0	0	0	0	2	2	1	0	0	0	0	0	0	0	0
H	.5	0	0	0	1	0	0	1	0	0	0	2	0	1	0	0	0	0	0	0	0	0
E	.4	0	0	0	0	0	0	1	1	0	3	2	1	1	0	0	0	0	0	0	0	0
R	.3	0	0	0	0	0	0	0	1	0	4	1	1	1	0	0	0	0	0	0	0	0
	.2	0	0	0	0	0	0	0	2	2	3	1	0	0	0	0	0	0	0	0	0	0
	.1	0	0	0	0	0	0	0	1	2	1	1	0	0	0	0	0	0	0	0	0	0
	.1	0	0	0	0	0	0	0	2	1	1	0	1	0	0	0	0	0	0	0	0	0
	.2	0	0	0	0	0	0	1	1	1	1	0	1	1	0	0	0	0	0	0	0	0
L	.3	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0
O	.4	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
W	.5	0	0	0	0	1	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0
E	.6	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
R	.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	.8	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UNDR		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTL		0	0	0	1	2	4	8	12	8	13	10	7	6	0	0	0	0	0	0	0	0

Source: University of Wisconsin-Madison 1975.

MEAN MONTHLY LAKE LEVELS

Finally, the WRM computer program lists chronlogically simulated mean monthly levels for any particular lake and any designated pair of regulation plans from 1900 through 1973. The lake levels (feet IGLD) for the two plans and their difference are grouped together according to month and year. For example, the circled numbers in Table 39 correspond to the circled numbers in Table 38. The table indicates that, while the level of Lake Superior in January 1965 would be 599.34 feet if Plan SO-901 were in effect, that level under BOC conditions would be 600.31 feet. Thus, the Plan SO-901 level is 0.97 feet less than the BOC level.

TABLE 39 SIMULATED MEAN MONTHLY LEVELS ON LAKE SUPERIOR (PLAN SO-901 VS BOC, 1965-1970)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		Year
SO-901	599.34	599.13	599.03	599.13	599.52	599.83	599.94	600.07	600.24	600.30	600.28	600.19	4*	1965
BOC	600.31	600.10	600.00	600.08	600.46	600.80	600.88	600.94	601.06	601.08	601.02	600.91	4	1965
Difference	-.97	-.97	-.97	-.95	-.94	-.97	-94	-87	-.82	-.78	-.74	-.72		
	599.98	599.76	599.70	599.83	600.05	600.21	600.28	600.45	600.44	600.31	600.19	599.96	4	1966
	600.70	600.48	600.42	600.55	600.77	600.90	600.91	600.98	600.92	600.80	600.70	600.50	4	1966
	-.72	-.72	-.72	-.72	-.72	-.69	-.63	-.53	-.48	-.49	-.51	-.54		
	599.82	599.69	599.58	599.80	600.04	600.22	600.47	600.63	600.57	600.46	600.39	600.18	4	1967
	600.32	600.15	600.04	600.24	600.52	600.68	600.84	600.90	600.79	600.66	600.56	600.32	4	1967
	-.50	-.46	-.46	-.44	-.48	-.46	-.37	-.27	-.22	-.20	-.17	-.14		
	599.97	599.77	599.71	599.98	600.27	600.58	601.02	601.29	601.45	601.51	601.27	600.98	4	1968
	600.06	599.81	599.71	599.98	600.34	600.74	601.22	601.50	601.66	601.70	601.46	601.16	4	1968
	-.09	-.04	.00	.00	-.07	-.16	-.20	-.21	-.21	-.19	-.19	-.18		
	600.88	600.77	600.57	600.66	600.92	601.02	601.09	601.22	601.21	601.03	600.85	600.62	4	1969
	601.07	600.95	600.75	600.84	601.10	601.19	601.20	601.20	601.05	600.80	600.56	600.30	4	1969
	-.19	-.18	-.18	-.18	-.18	-.17	-.11	.02	.16	.23	.29	.32		
	600.43	600.26	600.06	600.12	600.54	600.86	601.03	601.09	601.05	601.15	601.22	601.13	4	1970
	600.06	599.88	599.72	599.81	600.28	600.68	600.89	600.96	600.89	600.92	600.94	600.84	4	1970
	.37	.38	.34	.31	.26	.18	.14	.13	.16	.23	.28	.29		
	600.86	600.71	600.69	600.80	601.13	601.40	601.47	601.43	601.33	601.35	601.32	601.10	4	1971

* 4 represents Lake Superior

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